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# Estimating Rail Cost for Multimodal Corridor Planning

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**Estimating Rail Cost for Multimodal Corridor Planning**

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# Abstract

## Estimating Rail Cost for Multimodal Corridor Planning

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This study evaluates specific variables that influence rail freight operating costs for line haul movements. This paper gives planners a mechanistic method to determine rail costs on a single corridor while analyzing the effects of different variables on the overall operating costs. Planners evaluating the benefits of rail operations face two problems; what is the route alignment and what rail costs are derived for this alignment? This paper also reports on a promising method to measure track alignment—specifically grades – which obviates the need to work with railroad companies to determine track alignments for preliminary multimodal analysis. Complete rail freight transportation assessment can be determined from the proposed two methods, allowing more accurate planning to be done in the area of freight movement.

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# Chapter 1: Introduction

The United States has an extensive freight transportation system in which rail is playing an increasingly important role to moving all commodity flows – exports, imports and internal long-haul domestic routes. Rail demand is estimated to increase at least 37% by tonnage and 86% by value (FAF 3, 2012) between now and 2040 and can handle this demand if investment to remove various bottlenecks is undertaken, in combination with longer trains and sidings, and track improvements (Cambridge Systematics, 2007). In addition, further modal shifts to rail on shorter routes are expected, as a result of environmental and energy benefits (TRBNRC, 1998). Finally, studies have indicated that "a truck-rail container movement can yield much greater cost savings compared with truck alone if the cost of the transfer is offset by rail's lower cost per ton mile" (TRBNRC, 1998; Resor et al., 2007; Seedah et al., 2011). But how do transportation planners, when considering a greater role for rail in state and regional transportation freight flows, estimate rail costs so that they can see at which point rail is more efficient than trucks on key corridors?

Shippers consider a multitude of variables when determining freight mode choice (Prozzi et al., 2011; Cottrell, 2008; Harrison et al., 2011; Lubis et al., 2003). Studies show that operating cost and delivery times (Prozzi et al., 2011; Cottrell, 2008; Harrison et al., 2011; Lubis et al., 2003).) are important variables and should be prime outputs of any planning model which estimates shipper choice. Current mode choice and other planning models do not capture the effects of weight, speed, engine power, grade, or curvature—key elements of any mechanistic approach – on operating cost and delivery times. Furthermore the literature review revealed that (a) cost variables are incorporated in an aggregate manner resulting in poor predictions of the effects of cost-related policies,

(b) none of the current models considered the dynamics of fuel cost, (c) most of the input data is out-of-date and/or proprietary, and (d) most model applications are confined to larger-scale study areas.

This study provides the necessary components for building a mechanistic rail model to assist in addressing this gap and describes a rail costing toolkit which can be utilized by planners. The output of the toolkit allows planners to compare rail service on freight corridors in terms of overall cost, fuel costs, emissions per ton-mile, and related secondary costs such as pick-up and delivery costs.

This thesis report is structured as follows. Chapter 2 presents a detailed literature review of freight movement in Texas, and the variables that need to be considered when estimating intermodal freight rail costs. Chapter 3 describes current rail models including limitations and improvements that can be made to existing models. Chapter 4 explains the methodology on the newly developed rail model. Chapter 5 discusses rail alignments as well as Hay's (1982) method of the location process and how it can be used in rail modeling. Chapter 6 is dedicated to case studies and sensitivity analysis of key variables.

# Chapter 2: Literature Review

Freight moves in a variety of ways, often involving multiple modes. The focus of the logistics industry has expanded from regional routing optimization in the 1960s to embrace global supply chains covering the efficient movement of traded commodities. There are, of course, a variety of factors behind mode choice but the leading one, for most non-airborne commodities, is cost per ton-mile. Ships, by definition, monopolize the waterborne element of global trade and costs are influenced by route length, speed, vessel size, and possible tolls, such as those for passage through the Suez and Panama canals. Goods landed at marine terminals must be delivered and delivery is carried out in the United States by truck and rail modes, often working together. They compete on routes that link all major markets and freight flows on both modes use high density corridors. Rail companies use double-tracked transcontinental routes to move goods across the country; in Texas, however, less than twenty percent of the on-system highway network carries over seventy percent of the truck ton-miles. Texas highway investment is falling and it is unlikely that additional miles, even on heavily used highways, will be easily funded over the next decade. So can rail operations offer a truck-competitive service over key Texas corridors?

Rail costs are influenced by handling costs that increase the route mileage at which rail costs can compete with trucking. Researchers have estimated this breakeven point and, although it is falling, in the literature it remains in the 500-to-700 mile range depending on commodity value and increased fuel costs. However, events are changing in favor of rail. Recently, rail has benefited from rail profitability, track investment (double tracking and longer sidings), longer and heavier trains, and terminal efficiencies. These have made rail more competitive and profitable. Moreover, rail is much cleaner in terms of ton-mile emissions, which, although not currently valued in the price of rail service, does beneficially impact air quality.

## 2.1 FREIGHT MOVEMENT IN TEXAS

A comprehensive study by Prozzi et al. (2011) documented freight movement in Texas. The study found that freight movement is a necessity for the economy in order for products and goods to be safely, reliably, and efficiently moved between markets. For Texas this includes production and consumption centers as well as products in the energy industry. Freight movements in Texas have shown strong increases due to population and economic growth. Texas also contains extensive trade corridors which make the freight movement structure and infrastructure critical. The Texas economy must be further discussed and explained to better understand freight movements (Prozzi et al., 2011).

Texas is usually known for the dominance in the energy industry, in particular oil and gas. Although this is a large part of the economy, Texas is diverse in many other areas that continue to grow. The economy can be broken down into four major goods sectors including construction, mining and logging, manufacturing, and trade and transportation. Trade and transportation are the largest portion of the Texas economy, which is expected to more than double by 2035 (Prozzi et al., 2011). Freight movement will be a large factor in the growth of the economy as well as its sustainability.

Determining freight demand flows across a state network is challenging. It is necessary to evaluate where and how these flows are distributed in order to “determine the impact of freight on the infrastructure, improve freight mobility, forecast system performance, and improve safety” (Prozzi et al., 2011). In particular, evaluating both truck and rail modes provide good insight to the freight systems performance and characteristics especially in Texas where these modes dominate the market.

Texas has an extensive transportation system that facilitates the movement of freight. This system includes port facilities, railways, highways, pipeline infrastructure, and airports. There are also 11 direct land ports of entry between Texas and Mexico for international ground trade (Prozzi et al., 2011). Over 64% of the total freight tonnage was moved by rail, truck, or some combination of the two modes for all freight movement in Texas in 2007 (Prozzi et al., 2011).

Some of the main highways of Texas including IH 35, IH 10, IH 20, IH 37, and IH 45 are the most used routes for truckers. Between now and 2040, it is estimated that truck tonnage within Texas will increase by 60% (Prozzi et al., 2011). Any increase in freight transportation could impact traffic congestion, safety, and infrastructure deterioration on these highways (Prozzi et al., 2011). Other possible impacts include security, environmental issues, and quality of life. With increase in truck volumes and an unchanging highway capacity, it can be assumed that the level of service of these highways will decrease. Although the current Texas highway system is vast, capacity issues will continue to be a challenging problem for trucks in the state. Trucks are an essential part of the system because trucks are involved in most rail and air supply chains.

The rail system in Texas plays a key role in linking the economy to other states and getting products to and from the ports. International and interstate economic business depends on the rail system and infrastructure of Texas. Between now and 2040 it is estimated that rail tonnage within Texas will increase by 75% (Prozzi et al., 2011). The rail infrastructure is most important for interstate trade because of the efficiency of rail over long hauls. Chemicals and coal are the two products that are transported the most by rail first because of safety and second because of cost (Prozzi et al., 2011).

Three rail companies, Union Pacific, Burlington Northern Santa Fe Corporation, and Kansas City Southern own and operate the major Class 1 rail lines in Texas. Houston is the most important rail hub in Texas accounting for most of the rail activity in the region (Prozzi et al., 2011). Freight rail demand is also expected to exceed the capacity on many of the corridors in Texas if the infrastructure remains the same. However, possible modal shifts can be expected toward rail in freight transportation because of the benefit in environmental and energy challenges.

The desire for connectivity of goods through supply chains has increased with globalization. The role of shippers has especially increased to the point where they are the predominant decision makers in the global market. Freight transportation is continuously evaluated by shippers who monitor and modify these supply chains. The ability of a freight mode to be fast, safe, reliable, and inexpensive are all key components of freight transportation. Most of these characteristics can be a function of the capacity of the infrastructure, and the different technologies of the specific modes. Depending on the goods needed to be shipped and the shipping distance, shippers decide which mode to use. Prozzi et al.'s (2011) study showed that service availability, on-time reliability, minimal loss and damage, and prompt pick-up and delivery are some of the most important factors to shippers. This study concluded that the focus should be simply the characteristics of the commodity instead of which mode would work best for them. Sometimes multi-modal options is best suited the shipper's needs.

### 2.2 Review of Factors Influencing Intermodal Costs

The Transportation Research Board National Research Council in 1998 discussed and researched policy for intermodal freight transportation in the United States. It was found that "a truck-rail container movement can yield much greater cost savings compared with truck alone if the cost of the transfer (the cost of the added handling of the container plus the costs of the difference in speed and reliability between truck and intermodal) is offset by rail's lower cost per ton mile" (TRBNRC, 1998). In addition, the report also underscored the environmental benefits of intermodal transportation because rail generates lower emissions per ton mile than trucking. "Some state departments of transportation have been attracted by the potential of truck-rail intermodal for relieving pressure on state highway systems and have considered state investments in intermodal facilities as possibly cheaper alternatives to highway expansion" (TRBNRC, 1998). The Council concluded that four areas to improve intermodal freight policy include principles for government involvement, federal surface transportation programs affecting freight, regulatory and operations issues, and public finance of intermodal freight (TRBNRC, 1998).

Further studies by Prentice (2003) and Harrison et al. (2010) also address the importance of intermodal connectivity and bottleneck elimination. Prentice (2003) observed that efficiency and accessibility are two of the main challenges of intermodal freight transportation. Transportation by rail when considering intermodal freight movement helps shippers compete in cost and time. However, bottlenecks can be an issue for intermodal transport which make scheduling and the logistics much more complex and therefore costly. Congestion and queues that stem from bottlenecks are not only an infrastructure problem but an operational problem as well. If enough time and money is spent, most bottlenecks can be at least relieved or moved (Prentice, 2003). Prentice recommends that supply chain dysfunctions are to be researched to solve these bottleneck issues instead of spending resources only improving infrastructure.

Harrison et al.'s (2010) intermodal traffic study of Texas and the Southwest also identified rail bottlenecks as one of the causes of stifled intermodal growth in the region

(Harrison et al., 2010). Rail intermodal service in Texas has many strengths, weaknesses, opportunity, and threats associated with it. The type of products that are being shipped by both rail and truck are important to the intermodal service. However, other factors including annual growth rates, tonnage, and revenue are also important to this growing industry and the outcome of the future of rail (Harrison et al., 2010). .

Operating cost estimates of transportation modes provide a realistic approach to determine how shippers and freight movers make decisions concerning route choice, mode choice, delivery times and frequency of delivery. Shippers are rational and will make decisions that lower operating cost and raise profits. Conditions of the transportation network such as congestion may influence which routes are used and the time of delivery. Key components such as weight, speed, engine power, grade, or curvature—key elements of any mechanistic approach –which influences operating cost and travel time of both trucking and rail modes (Cottrell, 2008; Harrison et al., 2011; Lubis et al., 2003). Moreover, they are incapable of fully internalizing external or social costs into their calculations.

Harrison et al. (2010) therefore recommend that it is necessary "… to link the modal components together in a single cost model which would allow planners to replicate, at the basic level, the operations of logistical departments and companies who manage the supply chains of companies that use the services provided by the various modal providers." Using this approach will enable planners to accurately identify problem areas and effectively allocate scarce resources to these areas to relieve bottlenecks in the system.

## 2.3 Factors Influencing Rail Costs

Transportation Research Related studies by Cambridge Systematics (2007), Morgan et al. (2007) and Fekpe (2010) address freight rail mobility constraints. Cambridge Systematics (2007) identifies the need for new rail tracks, signals, bridges, tunnels, terminals, and service facilities to enable the U.S. rail infrastructure handle growth over the next few years. "The U.S. DOT estimates that the demand for rail freight transportation, measured in tonnage, will increase 88 percent by 2035" (Cambridge Systematics, 2007). Thus, in order to attract truck movements to rail, further work needs to be done to determine the capacity and investment that is needed to increase the tonnage moved by rail, and reduce the rate of growth of truck traffic on highways (Cambridge Systematics, 2007). Morgan et al. (2007) examined rail systems in the United States to determine good practices for relocating, expanding, and developing rail and their associated policies in the urban areas of Texas. Rail relocation proved to be a vital part of the long-term strategy to address urban transportation system changes and provide economic opportunities. Alternative corridors or improvements in existing corridors can also highly benefit congestion problems especially in urban areas (Morgan et al., 2007).

Fekpe's (2010) study addressed freight mobility constraints for the rail system including low-cost improvements. Fekpe (2010) states that railroads are beginning to encounter capacity constraints especially when freight is shared with a passenger rail system. This issue has been seen in areas of the US where high speed rail is desired. Certain upgrades such as track improvements, communication systems, pairing mainlines, and the joint uses of facilities are a necessity to maintain the current mobility of trains (Fekpe, 2010). Variables affecting these recent constraints and capacity issues include speed, length of trains, idle time, level of service, terminal dwell time, and on-time customer pickup or delivery (Fekpe, 2010).

A recent update from the American Association of Railroads (2011) suggests that the current weights of costs in the rail industry are changing. While labor continues to dominate the majority of the costs for rail, fuel is increasing rapidly. Just in 2010, the percentage spent on fuel increased from 14.9% to 18% while labor decreased by over 1% (AAR, 2011). Other smaller factors include materials/supplies, equipment rentals, depreciation, and interest (AAR 2011). All of these other factors still only contribute about 45% of the total costs. Each quarter these numbers are updated allowed for trends to be observed and recorded.

Table 1: Current Weights of Costs in the Rail Industry (AAR, 2011)

| | 2008 | 2009 | 2010 |
|---|---|---|---|
| Labor | 30.2% | 34.7% | 33.3% |
| Fuel | 25.2% | 14.9% | 18.0% |
| M&S | 5.1% | 5.1% | 5.0% |
| Equipment Rents | 6.3% | 7.1% | 6.2% |
| Depreciation | 10.4% | 13.9% | 12.8% |
| Interest | 2.3% | 3.0% | 2.9% |
| Other | 20.5% | 21.3% | 21.8% |
| Total | 100.0% | 100.0% | 100.0% |

In a study by Seedah et al. (2010) many variables were found to contribute to the costs of transportation by rail and must be accounted for when performing any cost analysis. According to Seedah et al. (2010), rail costs can be divided into 8 categories including cargo weight, locomotive selection, "train in motion" calculations, fuel consumption, locomotive emissions, crew labor costs, maintenance costs, and capital/investment costs. These variables were found to be essential to accurately estimating rail costs. An initial 2009 case study performed in the study demonstrated the economic benefits of different levels of intermodal rail service in competition with direct highway truck movement. The study determined that high terminal loading and drayage costs for a corridor trailer truck type intermodal rail movement can be partially offset by the line haul economics of double stacking container even at higher train speeds.

Another study conducted by Resor et al. (2004) involving short-haul rail movement included costs breakdown consisting of crew, locomotive, car, fuel, and track maintenance cost. A cost of movement per TEU was then developed for specified routes in the study. Resor et al. (2004) found that track maintenance cost was the largest portion of total line haul cost at 35%. Furthermore, it was also determined that high terminal costs prevented the rail industry from being competitive with trucks and therefore should be the focus of any research or improvement (Resor et al., 2004).

In a paper by DeSalvo (1967), it was recommended that rail freight transportation be divided into various processes including assembly, line-haul, and loading and unloading. The line haul process, further studied in this paper, showed vast variances in costs depending on the locomotive, route, and tonnage. It was determined that long hauls and short hauls can be very different and should be evaluated in a separate manner (DeSalvo, 1967).

Track design factors – comprised of grade, curvature, and rise and fall – are found to influence track resistance, grade resistance, curve resistance and train resistance, and consequently fuel consumption and cost. These factors are further explained and discussed by Hay (1980). Grade resistance is probably the most important factor in most route designs (Hay, 1980). “This can have an impact on the number of trains, locomotive units, and horsepower to move a given tonnage, on speed and schedule time, on locomotive utilization, and consequently, on costs" (Hay, 1980). Curvature is also important when designing curves because minimizing the curve resistance will increase the train efficiency and reduce the amount of energy required to move through the curve. This resistance is developed by friction between the flanges and the treads of the wheels (Hay, 1980). Rise and fall gradients can be divided into classes in which the gradient either forces the operator to apply acceleration or braking, or only minor variation in speed results (Hay, 1980). When designing a new track, these factors must be considered in order to achieve long term efficiency and cost effective rail transportation.

In addition, Hay (1980) suggests that tonnage rating[1] is the most important factor when deciding the appropriate locomotive to use on a haul. Not only can the tonnage rating help decide which locomotive to choose but also which route to take. Tonnage rating gives an estimate of the horsepower which will then give an insight to the size of locomotive required, and the maximum and minimum speeds that can be travelled over a specific route (Hay, 1980). All of these factors consequently affect the costs of the trip.

Information regarding pollution by locomotives has been gathered by The Environmental Protection Agency. According to the agency, the engines are only required to meet modest regulations set in 1997 (EPA, 1997). The Clean Air Nonroad Diesel Rule set in 2004 has helped tremendously with reducing particulate matter. Standards will continue to be set and enforced to improve the public health and reduce air emissions.

Technological advancements are also making intermodal transportation of freight to become more efficient and viable while achieving the lowest costs and most beneficial

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[1] Tonnage rating is the tonnage which can be hauled at a specified minimum speed over a given territory. (Hay, 1980)

environmental impact (TRBNRC, 1998). Machalaba (2011) discusses the impact that technology is having on the freight rail community as well as the possible upsides it can have for the future. Digital technology is becoming more prevalent in rail and soon will be able to ensure the safety of the train as well as keeping a tight schedule (Machalaba, 2011). Two of the more recent technological breakthroughs have been the development of Positive Train Control (PTC) and Electronic Controlled Pnuematic (ECP) brakes. PTC allows a central control system where the control station can remotely control the train if necessary (Machalaba, 2011). ECP is a brake system that is controlled by electronic signals instead of air pressure which can improve handling and shorten braking distance (Machalaba, 2011). As technology develops, rail systems will become more efficient and much more reliable.

In the area of rail planning, complex models have been developed to determine the benefits and costs associated with rail investments. For example, Lubis et al. (2003) researched a freight network plan that could be utilized for a complex multimodal system. Using decision based models and non-decision making models, flows and capacity issues were evaluated for both rail and highway networks in Indonesia. It was determined that it was more beneficial to expand the rail system than continue to expand the road network (Lubis et al., 2003). Another study by Arnold et al. (2003) addressed the modeling aspect of a rail/road intermodal transportation system using a "… linear programing formulation to the hub-type problem based on multi-commodity fixed charge network design problems", and focused specifically on comparing rail to truck (Arnold et al., 2003). The authors suggest that the location of the intermodal terminal is the most important factors when determining which modes are more efficient (Arnold et al., 2003). Multimodal transportation is also very sensitive to the transfer or transshipment costs and can easily affect the modes feasibility (Arnold et al., 2003). Chen et al. (2010) assessed the performance of intermodal transfers at cargo terminals using a model that coordinates cargo transfers to improve efficiency and reduce total transportation costs (Chen et al., 2010). Advantages of using this type of model are to concentrate cargo to faster routes, utilize the existing infrastructure, and reduce the requirements for warehouses and storage areas with poor connections. Some of the variables considered are total system costs, operating costs, cargo dwell time, loading and unloading costs, cargo processing costs, and cargo transfer costs (Chen et al., 2010). This model is able to further assess efficiency advantages in the terminals and during transfers. Further development and case studies with this model should improve efficiency of intermodal freight terminals making intermodal transportation much more viable and cost effective.

A study by Southworth et al. (2000) explains the need for intermodal and international freight network modeling. Integrating multimodal and transcontinental networks can be useful when evaluating the freight network. Recent GIS technology can be used to improve logistics not only in a corridor but for international freight transportation (Southworth et al., 2000). A case study with tens of thousands of origins and destinations both within and across US borders was conducted. Another model developed by Lai et al. (2009) evaluates capacity and is able to consider future demand, compute line capacity, and even budget investment costs. This tool utilizes subdivisions characteristics to evaluate different impacts (Lai et al., 2009). After running some test cases, this model showed very good cost estimates of capacity expansion alternatives and also gives an output of delay vs. volume, total delay, average delay, and level of service. This model can help planners with capacity for developing rail alternatives based on network characteristics, demand, and budget.

Based on reviewed literature, elements identified to influence rail movements and costs include:

- Track Design
    - Grade
    - Curvature
    - Rise and Fall
- Tonnage
- Train Speed
- Length of Train
- Idling at sidings
- Terminal Dwell Time
- Trip Delays
- Terminal Operations Costs
- Fuel
- Labor
- Capital investment costs
- Cost of maintenance
- Bottlenecks
- Annual growth rates
- Emissions
- Track Capacity
- Overhead Costs
- Scheduling
- Empty car traffic
- Switching
- Freight Car Rental

Table 2 shows a breakdown of the literature and the variables associated with freight rail. Tonnage, terminal costs, capacity, and cost of expansion are the variables of highest interest to the rail industry and considerable research has been performed in those areas. Out of all 18 sources, at least 6 of them discussed these variables. Both track design and bottlenecks were also common among the sources with 5 sources for each of these variables. Having a variety of sources discussing each of these variables gave many perspectives and methods of considering these variables and helped decide which factors are necessary to consider for the rail mode.

Table 2: Rail Variables and the Associated Literature

| | Track Design (Grade, Curvature, Rise and Fall) | Tonnage | Train Speed | Length of Train | Idling at sidings | Terminal Dwell Time | Total Trip Delay | Terminal Operations Costs |
|---|---|---|---|---|---|---|---|---|
| AAR (2011) | | | | | | | | |
| Arnonld et al. (2003) | | | | | | ✓ | | ✓ |
| Cambridge Systematics (2007) | | ✓ | | ✓ | | | | ✓ |
| Chen et al. (2010) | | | | | | ✓ | | ✓ |
| DeSalvo (1967) | ✓ | ✓ | | | | | | ✓ |
| Fekpe (2010) | | | ✓ | ✓ | ✓ | ✓ | | |
| General Accounting Office (2003) | | | | | | | | |
| Harrison et al. (2010) | | ✓ | | | | | | |
| Hay (1980) | ✓ | ✓ | ✓ | ✓ | | | | ✓ |
| Lai et al. (2009) | | | | | | | ✓ | |
| Lubis et al. (2003) | | | | | | | | |
| Machalaba (2011) | | | | | | | | |
| Morgan et al. (2007) | ✓ | | | | | | | |
| Prentice (2003) | | | | | | | | |
| Prozzi et al. (2006) | | ✓ | | | | | | |
| Resor et al. (2004) | ✓ | | | | | | | ✓ |
| Seedah et al. (2010) | ✓ | | | | | | | |
| TRB National Research Council (1998) | | ✓ | | | | | | |

Table 2 continued: Rail Variables and the Associated Literature

| | Fuel | Labor | Capital investment costs | Costs of expansion | Cost of maintenance | Bottlenecks | Annual growth rates | Emissions | Track Capacity |
|---|---|---|---|---|---|---|---|---|---|
| AAR (2011) | ✓ | ✓ | | | | | | | |
| Arnonld et al. (2003) | | | | | | | | | |
| Cambridge Systematics (2007) | | | | ✓ | ✓ | | ✓ | | ✓ |
| Chen et al. (2010) | | | | | | | | | |
| DeSalvo (1967) | | | | | | | | | |
| Fekpe (2010) | | | | ✓ | ✓ | | | | ✓ |
| General Accounting Office (2003) | | | ✓ | | | | | | |
| Harrison et al. (2010) | | | | | | ✓ | ✓ | | |
| Hay (1980) | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ |
| Lai et al. (2009) | | | ✓ | ✓ | | | | | ✓ |
| Lubis et al. (2003) | | | | ✓ | | | ✓ | | ✓ |
| Machalaba (2011) | | | | | | | | | |
| Morgan et al. (2007) | | | | ✓ | | ✓ | | | ✓ |
| Prentice (2003) | | | | | | ✓ | | | ✓ |
| Prozzi et al. (2006) | | | | ✓ | | ✓ | | ✓ | |
| Resor et al. (2004) | ✓ | ✓ | | | | | | | |
| Seedah et al. (2010) | ✓ | ✓ | ✓ | | ✓ | | | | |
| Transportation Research Board National Research Council (1998) | | | | | | ✓ | | ✓ | |

## 2.4 CHAPTER SUMMARY

Creating a planning tool to evaluate the interplay of key variables is essential if planners are expected to understand the role that freight rail can play in supplementing economic growth (since much of rail operations are privately owned). A publicly available tool to easily analyze rail freight is essential. These operations are extremely difficult to model and can change vastly over time making it necessary to create a user-friendly and highly adjustable tool that can account for changes in prices, technology, and other variables.

Finally, an implementation of the concept to corridor planning will be a great improvement to the current freight movement system. Examining freight movement from this perspective allows planners to see the system as a whole and improve it along specific corridors. This will also give insight to the strengths and advantages of shipping by rail as opposed to other modes such as trucking. US freight is moved on both domestic and global supply chains, through which international ports and gateways which connect origins to destinations in the most efficient manner. These connections and corridors must be evaluated and planned to maximize the efficiency of shipping freight.

In the next chapter, a review of current rail models - including their capabilities and limitations is discussed.

# Chapter 3: Current State of Rail Models

Planners encounter difficulties in estimating rail line haul movement operations for specific corridors due to inadequate data and a limited insight into how railroads function. Actual rail cost models are few in number and can require finesse in deriving good estimates. Few rail models are available that are current and effective for today's rail freight movement. Government agencies such as the Surface Transportation Board (STB) are limited in the types of tools they traditionally use. As an example, the Uniform Rail Costing System (URCS), developed in 1938, used by STB to estimate variable and total unit costs for rail rate comparison is outdated and does not capture new rail technologies, fuel use, environmental impacts of rail, and rail improvement strategies. It is extremely difficult to determine public policy strategies and economic impacts of rail service changes using URCS.

The Train Energy Model (TEM), developed by the Association of American Railroads, is an extensive train simulator that can predict train performance on any route and predict fuel consumption (Painter, 2004) and other output. Unfortunately, it has limited utility for transportation planning since its proprietary license precludes any modifications to capture rail operational factors relevant to specific corridors. RailSim, another proprietary model, uses a Train Performance Calculator to determine trip times, line capacity, power and energy consumption, rail alignment alternatives, and even trip stops (RailSim, 2012). Despite its capabilities, it also cannot be publicly modified or extended for integration into mode choice models because of its proprietary license.

An alternative model is CTRail, a mechanistic intermodal rail cost model that enables stakeholders to measure operational differences between trailer on flat car (TOFC) and double-stacked containers in intermodal service. It allows for the calculation of gallons of fuel consumed, greenhouse gas emissions produced, the effect of operational differences when using multiple locomotives or car types, and the influence of delay, and other route specific characteristics such as grade changes and road curvature. The primary equations governing that model were adapted from work by DeSalvo (1967), Hay (1982) and Avallone et al. (2006). CTRail is limited in its ability to determine rail operating variables.

The following models are described in detail including the limitations and improvements that can be made to the models. Descriptions of the models are taken from existing literature and cited accordingly.

### 3.1 RAIL COST MODELS

***Uniform Rail Costing System[2]***

Uniform Rail Costing System (URCS) is the Surface Transportation Board's (STB) railroad general purpose costing system that is used to estimate variable and total unit costs for Class I U.S. It is the official tool used by the STB and serves as its first point of reference for rail operations studies. The URCS model can be used for costing specific traffic with less concern for economic characteristics (Bereskin, 2001). URCS uses system average units based on costs relationships and system data for Class I railroads. The data is updated annually by the STB; however, the basic structure of the model remains as it was when it was developed decades ago and does not reflect modern railroad operations. For example, there is no clear way to delineate double-stack intermodal as this technology was not widespread at the time of the model's development. For several reasons, the cost estimation method used by URCS is not entirely accurate. Four primary problems have been identified by researchers. First, the

[2] Taken from Seedah, Dan and Robert Harrison (2010), "Export Growth, Energy Costs, and Sustainable Supply Chains," Southwest Region University Transportation Center Report No. 476660-00069-1.

model uses linear “percent variable” equations to allocate expenses to specific operating activities based on a cross-sectional regression of cost data against traffic data for the Class I railroads of the 1980s, using a several-year time series. The equations therefore do not account for recent industry changes (e.g. mergers, increasing size, and traffic carried) which have affected operational costs of railroads (Bereskin, 2001). Furthermore, the linear nature of the model is contrary to the earlier stated finding that rail costs are non-linear in nature.

Secondly, URCS uses system averages based on data collected from Class I railroads. It “uses an accounting-based approach to costing, relying on annual operating expenses and traffic data reported by the railroads. This approach provides cost estimates on the average cost structure of individual railroads or regionalized groups of railroads. Average data on average railroad moves may not, in all cases, be appropriate for estimating a cost for a given railroad movement” (URCS Manual). System averages may not reflect the actual railroad rates charged by carriers, and may not reflect geographical location, technological improvements and system performance (AECOM, 2007). However, URCS gives users the flexibility of substituting cost data developed by the STB with user-generated cost.

The third primary problem with URCS is that it does not account for changes in fuel prices. The model does not have an input for fuel cost which we believe has a major influence in freight rail service rates.

Finally, URCS does not have the ability to estimate emissions produced during line-haul operations. This is essential for comparison with other transport modes like trucks and having this ability in a single model makes it easier for researchers to test different scenarios. Recently the STB announced its intention to begin the process of replacing the URCS model due to its well-known limitations. This initiative, taken under chairman-elect Mulvey started with a hearing at the STB on April 30, 2009.

***Train Energy Model***[3]

The Train Energy Model (TEM) developed under the AAR's Energy Program is a train performance simulator used to predict fuel consumption for any train on any route. It simulates the energy required to run a specific train over a specific route. Route data can be imported into the program and locomotive type, car type, lading weight and operating requirements for a consist can be specified. The program simulates the characteristics of the train over the route and the simulation acts in the role of an engineer by adjusting the throttle and brake applications to keep the train under the speed limit while avoiding unduly large draft and buff forces (Painter, 2004).

According to Painter (2004), train consists and ladings are configurable by using a graphical interface and different locomotive and car types can be chosen to replicate the consists seen in service. New car types that are not included in the program can also be created using graphical tools (Painter, 2004).

An additional feature in TEM is the ability to import routes based on actual data that includes speed limits, grades, and curves. These routes can then be used in the simulation of any consist that has also been created (Painter, 2004). The train control can be modified to simulate starts and stops or to limit operation to only a portion of the track segment.

After a simulation has been run, the train speed and track speed limit are displayed as a function of the milepost along the track for the segment simulated (Figure 1). Further information about the energy usage of the train and its speed at a given time is

[3] Recovering Railroad Diesel-Electric Locomotive Dynamic Brake Energy By Travis D. Painter B.S., University Of Illinois At Urbana-Champaign, 2004 Thesis, Urbana, Illinois. Available at

available to enable an in-depth analysis. TEM also produces a summary report which includes the "WORK DONE by EACH FORCE" which represents the energy produced by each simulated force acting on the train (Painter, 2004).

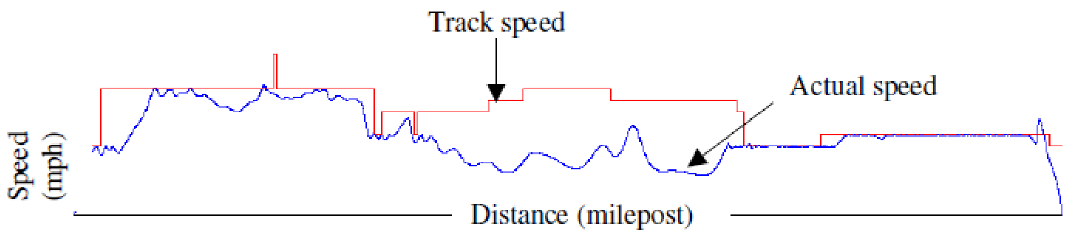


Figure 1: Example of Speed Profile Output from TEM (Painter, 2004)

Despite the capabilities of TEM, the software is not publicly available and the research team's efforts to obtain a copy were futile. The developers assert that the model is only available for railroads but can be used to validate new models.

***<u>Train Operation and Energy Simulator (TOES™)[4]</u>***

Train Operation and Energy Simulator (TOES™) simulates the interaction of train air-brake and ECP-brake systems, inter-car coupling behavior, locomotive performance characteristics, and train resistance forces. According to the TOES™ website, TOES™ has been validated numerous times in heavy North American freight trains and the software was applied to passenger and transit systems due to its ability to predict braking system response and stopping distance (AAR, 2008).

TOES™ "… allows the user to predict and analyze the response from various throttle and brake commands, and may be used to evaluate a vehicles response to in-train forces. The software applies a set of two complex operations: A non-linear fluid dynamics model of automatic and independent air brake systems and non-linear models

[4] http://www.aar.com/toes/downloads.asp

of friction draft gear and end-of-car cushioning units. TOES™ is therefore very useful in derailment prevention and analysis work. "

Typical TOES™ applications as listed on the website include accident or incident investigation; stopping distance investigations; coupler force monitoring; prediction of vehicle longitudinal accelerations; evaluation of train make-up strategies; evaluation of train handling studies; comparison of new track layouts; prediction of car fatigue damage; evaluation of new equipment; and examination of train make-up (AAR, 2008).

***CTRail***

CTRail a user-friendly mechanistic intermodal rail cost model developed by the Center for Transportation Research that enables stakeholders to measure operational differences between trailers on flat car (TOFC) and double-stacked containers in intermodal service. It allows for the calculation of gallons of fuel consumed, greenhouse gas emissions produced, the effect of operational differences when using multiple locomotives or car types, and the influence of delay, and other route specific characteristics such as grade changes and road curvature.

The initial intermodal model is mechanistic in nature and uses as inputs various factors such as cargo weight, energy consumption, and expert estimates of maintenance and crew labor costs. CTRail is divided into eight costing or analysis modules:

- Cargo Weight, Number of Containers, and Rail Car Configuration,
- Locomotive(s) Selection,
- Train in Motion Calculations,
- Fuel Consumption,
- Locomotive Emissions,
- Crew Labor Costs,

- Maintenance Costs, and
- Capital Cost and Investment Cost

These eight modules work together to provide cost estimates for line haul movement. An initial review of CTRail by William Huneke (Chief Economist) and Michael Smith (Economist) of the Surface Transportation Board, Dr. Carl Martland (Senior Research Associate [retired] at the Department of Civil and Environmental Engineering, Massachusetts Institute of Technology) and James Blaze, a rail industry expert, has yielded positive comments and encouragement.

According to Seedah et al. (2011), CTRail is limited to line haul movement operation and therefore does not account for terminal operations which include arrival operations, inspection operations, classification operations, assembly and disassembly operations, and the labor involved in the above operations (Seedah et al, 2011). In addition, capital investments such as road construction, right-of-way acquisition, grading, signal and interlock installation, stations and office buildings, and all other infrastructural investment cost are not included (Seedah et al, 2011). Other operational limitations of CTRail include an assumption of average speed instead of varying speeds at different sections of the track, assumption of full throttle operations without consideration for acceleration and decelerations, and omission of resistances caused by changes in grade, curvature, and wind resistance which are route specific. Locomotive idling is also ignored in the model except when calculating fuel consumption when a train stops at a siding. The model also assumes all the locomotives are identical and of the same horsepower which may not necessarily be the case as railroad companies may use different locomotives with different horsepower to optimize fuel consumption or enhance tractive effort (Seedah et al, 2011). Depending on the commodity type, railroad monopoly, and the route being used, railroad companies have additional charges such as switch charges, hazmat, and other charges not currently captured in the model. In addition, railroads install and maintain traffic signals, construct sidings, develop double tracks and spend on other capital investments which cannot be captured by this model.

Based on these limitations, CTRail – in its current form - can only be used for rail cost comparison purposes only and not for determining railroad rates. It is publicly available and thus provides an opportunity for future improvements by the research team.

***<u>Canadian National Parametric Model</u>***

In addition to CTRail, a publicly available rail capacity model developed by Canadian National (CN) offers a robust but simpler alternative to popular and expensive commercial model such as the Rail Traffic Controller (RTC). The CN parametric model provides a system-wide measure of subdivision capacity in a rail network and enables evaluation of the effect of improvements for various alternatives (Krueger, 1999). The resulting comparisons of capacity can be used to identify areas of limited (bottlenecks) or excess capacity.

The model measures the capacity of a subdivision by predicting its relationship between train delay (hours per trip) and traffic volume (trains per day). In general, the more trains that run on a subdivision in a given time period, the more delay each train experiences (Prokopy et al., 1975). The CN model calculates this relationship using several key parameters that affect the traffic handling capability of a subdivision. The CN model can be used in network capacity planning to monitor system track capacity and support short and long term planning. The biggest downside to this model is that it can only handle 75% of a double track. It is however publicly available.

### 3.2 Rail Model Recommendations

Based on the review of selected rail models, Table 3 was generated to match which models accounted for the rail cost variables discussed in the earlier sections. It can be inferred that CTRail and TEM meet most of the desired criteria. Both models are able to capture changes in track design, fuel consumption, tonnage, and train speed. These variables are necessary when simulating specific routes for analysis. However, TEM is propriety and thus cannot be accessed by the research team. Therefore, a combination of CTRail and CN's Parametric Model will form the core of the rail component of CTRIT. CN's Parametric Model captures the external parameters such as delay and track capacity and will be useful for determining bottlenecks and testing track improvements. Using the above selections as base models, further enhancements will be made to these models to ensure an accurate current model that can be used for freight rail planning purposes.

### 3.3 Chapter Summary

In summary, most available rail models are limited in their ability to incorporate into planning models because they are either proprietary software or built to be standalone applications. Publicly available models are also limited in scope, and need to be further developed to output accurate rail operating parameters. To address these limitations, CTRIT is being developed to combine both intermodal truck and rail operation models. These models contain features that account for the effects of cargo weight, running speeds, network capacity, and route characteristics on both truck and rail operations.

In the next chapter, an intermodal rail costing model is introduced to provide researchers with a tool to assist in further studies of rail operations. This tool is aimed at giving insight to the everyday operational costs and determining the comparative costs for different routes. In particular, the rail mode will be evaluated by analyzing specific corridors which is especially necessary when planning.

Table 3: Review of Selected Rail Cost Models based on Influence Factors

| **Variable** | **CTRail v. 1.0** | **URCS** | **TOES** | **TEM** | **CN Parametric Model** |
|---|---|---|---|---|---|
| Track Design (Grade, Curvature, Rise and Fall) | Yes | Distance Only | Yes | Yes | Distance Only |
| Fuel | Yes | | | Yes | |
| Labor | Yes | | | | |
| Tonnage | Yes | Yes | Yes | Yes | |
| Train Speed | Yes | | Yes | Yes | |
| Length of Train | Yes | Yes | | Yes | |
| Commodity Type | | Yes | | | |
| Track Capacity | | | | | Yes |
| Bottlenecks | | | | | Yes |
| Idling time at sidings | | | | Yes | |
| Terminal Dwell Time | | | | | |
| Switching | | Yes | | | |
| Total Trip Delay | | Yes | | Yes | Yes |
| Terminal Operations Cost | Yes | Yes | | | |
| Capital investment costs | Yes | | | | |
| Overhead Costs | | Yes | | | |
| Cost of maintenance | | | Yes | | |
| Freight Car Rental | | Yes | | | |
| Empty car traffic | | Yes | | | |
| Emissions | Yes | | | | |
| Current Status | 2010 | Model 1980s; Data 2009 | 2008, RR Members Only | RR Members Only | 1999 |
| License | Public | Public | Proprietary | Proprietary | Public |

# Chapter 4: Development of the Rail Model

Focusing on limitations of CTRail suggested some improvements and adjustments that need to be made to the model. As discussed earlier, CTRail is limited in its ability to determine rail operating variables. For example, it assumes the train is running at a user specified average speed instead of variable speeds caused by changes in grade, curvature, wind resistance, and traffic delays. In addition, CTRail always operates its train at full throttle, without consideration for acceleration and deceleration. The model also assumes all locomotives are identical and run at the maximum horsepower which is not always the case as railroad companies run locomotives at different horsepower to optimize fuel consumption or enhance tractive effort.

## 4.1 Rail Corridor Modeling

CTRail improvements were made to allow for the input of more detailed track and operating information regarding a specific route – essential elements for planners considering rail as an alternative to trucking. The improved model, called CTRIT, can determine fuel consumption based on the specific characteristics of the rail track such as elevations, grades, and curvature; and is capable of estimating trip delays through the integration of the CN's parametric model developed by Kruger (1999) and enhanced by Lai et al. (2009). It also allows for almost any combination of train characteristics such as type of car, type of container, cargo weight, number of locomotives, and HPTT (horsepower per trailing ton) ratio. Operating variables such as train crew, maintenance, and loading/unloading costs are also considered. The seven modules which make up CTRIT's rail model are:

- Track Data Acquisition (distance, elevation, speed, curvature),
- Equipment and Cargo Selection,
- Pre-Process Calculations,
- Locomotive Selection,
- Train-In-Motion Calculations,
- Travel Time, Rail Capacity and Delay Calculations, and
- An Output Module

These seven modules work together to provide cost estimates for line haul corridor movement. Further details for these modules are as follows.

### 4.1.1 Track Data

The user must first upload track data for the route of interest to begin rail analysis using CTRIT. This data is extremely basic but is often difficult to acquire. The first input is the distance or milepost data. This is basically incremental milepost data along the entire route. All rail routes in the United States do have this milepost data with some routes being harder to obtain than others. The associated elevation data and speed limit data for each distance (milepost) is also required. Curvature information is also strongly recommended when running this model.

The track data is used by the model to simulate train movement along the route to determine the necessary resistance forces required to move the train. The integrity of the track characteristic data is necessary for the accuracy of this model. Milepost, elevation, and curvature data remain the same over time for any particular section unless actual changes are made to the track. However, speed limit data varies frequently due to construction work, track maintenance, or incidents along the track where speed must be regulated. This makes speed data difficult to accurately estimate on any given day. It is therefore recommended that users assume that the acquired speed data is a reflection of general conditions on the track. CTRIT also enables users to segment routes using mileposts thus providing the ability to analyze specific segments of the route. The flexibility to segment tracks, allows users to not only capture the effect of freight rail movement on a corridor but by subdivision without compromising the integrity of the model as a whole.

### 4.1.2 Equipment and Cargo Selection

There are over five types of international containers that intermodal trains carry today, each having its own tare weight and maximum payload – 20 feet dry, 20 feet reefer, 40 feet dry, 40 feet reefer, and 45 feet H-Cube. CTRIT allows the user to select the desired container used for analysis based on these available options. In addition, there is a "no container" option which is useful in simulating piggy-back loads. Users can then specify the number of containers that will be transported as well as whether or not the containers are double stacked on the rail car. Double stacking the containers will simply increase the car weight but reduce the number of cars necessary for the trip. Each intermodal car type has unique characteristics such as tare weight, max payload, length, cost, and number of axles. CTRIT allows the user to select what type of car will carry the load and apply the characteristics of that car to the train that will be simulated.

By specifying the weight of the cargo, the user consequently determines the weight of the commodity being shipped. For example, a grain train will have a much higher cargo weight per container than a train carrying electronic parts. The model considers both the container and car maximum payloads when the user inputs the cargo weight. The cargo weight cannot exceed either of these maximum payloads as specified above. CTRIT also accounts for shipping empty containers which is common for the repositioning of equipment for the rail companies. This is done through a utilization ratio which is a percentage of full containers. Although this model cannot account for the exact position on the train of these empty containers, the total weight is still considered.

Once the car, container, and cargo selection is complete, the train characteristics can be calculated. This includes the total number of cars, rolling stock weight, and rolling stock length.

Given a certain number of cars, $N_c$, the total rolling stock weight, $W_s$, is determined as

$$W_s = \sum_{i=1}^{N_c} [c_i + d(x_i + k_i)] \tag{1}$$

where $c_i$ is the tare weight of one rail car, $x_i$ is the tare weight of one container, $k_i$ is the cargo weight, $N_c$ is the total number of cars, and $d$ equals 2 for double stacked containers or equals 1 for single stacked containers and trailer of flat cars.

For an intermodal service, given a certain number of containers, $N_{con}$, the total number of cars will be

$$N_c = \frac{N_{con}}{d} \tag{2}$$

where $d$ is as previously defined. Given a certain number of cars, $N_c$, the total rolling stock length, $L_s$, will be

$$L_s = \sum_{i=1}^{N_c} N_c l_s \tag{3}$$

where $l_s$ is the length of one rail car based on the selected car and its associated properties.

### 4.1.3 Pre-Process Calculations

By The Pre-Process module performs calculations prior to simulating train movement along the route to determine the necessary constraints and number of locomotives required to move rail cars. The calculations involve determining the maximum (governing or ruling) grade, the maximum resistance encountered, and the minimum horsepower required for the train to traverse the track. According to Hay (1982), ruling grade is an important factor when considering a train's route because this factor can limit the tonnage and give insight to the necessary train size. Ruling grade can be defined as the maximum gradient over which a train of certain tonnage and a given speed can be navigated (1982).

The ruling grade, maximum resistance and required horsepower are calculated at a specified incremental distance ("step distance") using the uploaded track data and the following algorithm.

**Step 1.** Get user-specified "step distance" in miles for iteration purposes

**Step 2.** Looping through the track data in increments of the "step distance," determine the front and back elevations of the train by linear interpolation.

**Step 3.** Calculate grade using the change in elevations divided by the length of the train.

**Step 4.** Using the calculated grade, determine the resistance encountered at that section of the route. Train resistance ($R_t$) is modeled using the Basic Davis Equation (1982) defined as

$$R_t = \left(1.3 + \frac{29}{\left(\frac{w_c}{A_c}\right)} + bV + \frac{cAV^2}{\left(\frac{w_c}{A_c}\right)*n}\right) * W_c * K_{adj} + W_C * 20 * G + W_C * .8 * C_v \quad (4)$$

Here, $R_t$ is the train resistance, $w_c$ is weight of a single car, n is the number of cars, $A_c$ is the number of car axles, $V$ is train speed, $A$ *is* car cross-sectional area, $b$ is the coefficient of flange friction, and c is the drag coefficient of air. $W_c$ is total weight of all cars, $K_{adj}$ is an adjustment factor to modernize the Davis equation, G is the grade for that section, and $C_v$ is the curvature for that section. These car properties were automatically used based on the car and container selection. Velocity ($V$) is assumed to be the maximum posted speed for that section which was obtained from the track data portion of the model.

**Step 5.** Determine the required train horsepower ($\mathrm{HP}_{required}$) using Equation 5 where $e$ is the engine efficiency of the locomotive - default is 82% (1982)

$$\mathrm{HP}_{required} = \frac{\mathrm{R_t{*}V}}{375*e} \quad (5)$$

**Step 6.** Store $\mathrm{HP}_{required}$ in a list, move to next increment of step distance and return to Step 3.

**Step 7.** Search through list of stored governing grades to determine the largest required horsepower required along the entire route.

### 4.1.4 Locomotive(s) Selection Module

By The total number of locomotives required is dependent on the horsepower of each locomotive and the desired horsepower per trailing ton (HPTT) ratio. HPTT ratio is determined by railroads, and varies by route and service type (Seedah et al., 2011). It dictates the desired maximum speed of the train (Seedah et al., 2011). The typical ratios used by Class I railroads varies between 2.5 to 3.5 HPTT ratio for intermodal and less than for other heavier cargo such as coal (Seedah et al., 2011). CTRIT enables the user to specify both the HPTT ratio and the size of locomotives. Properties associated with different sizes of locomotives such as the weight, length, and numbers of axles are incorporated into the model. The selected locomotives horsepower must exceed the minimum horsepower required as calculated in the Pre-Process section and multiplied by the HPTT ratio (Equation 6). The train's total horsepower is therefore equivalent to:

$$Total\ HP\ Required\ =\ HP_{required} \times HPTT_{ratio} \tag{6}$$

Given the weight of a single locomotive ($w_{l_i}$), and the number of locomotives ($\mathrm{N_L}$), the total weight of all the locomotives is equal to $W_L$. The total weight of the train is then equal to $W$, which is the sum of the rolling stock weight and the locomotive weight.

$$\mathrm{W_L} = \sum_{\mathrm{i=1}}^{\mathrm{N_L}} \mathrm{w_{l_i}} \tag{7}$$

$$W = W_s + W_L \tag{8}$$

### 4.1.5 Train in Motion Calculations

The Train-In-Motion module simulates the train traveling over the route to determine the resistance encountered, horsepower needed, running speeds achieved, and fuel consumed at each step distance along the route. According to Hay (1982), train movement and speed are opposed by resistances that must be overcome by propulsive force (also called tractive effort) of the locomotive. Wind resistance, external axle loading resistance, curve resistance, grade resistance, acceleration resistance and inertia (starting) resistance are only present intermittently but are also estimated through empirical relationships (1982).

#### 4.1.5.1 Resistance and Power

CTRIT aims to move the train by some specified incremental distance – “step distance” similar to that specified in the Pre-Process module. The locomotive and car resistances are then calculated to find the total resistance for each incremental step using Equation 4. Current posted speed limits are used in determining the minimum required horsepower $HP_{min}$, via Equation 5. The train’s actual running speed $V_i$ is then solved iteratively using the Equation of Motion (Eqn 5) defined as $f(V_i)$ and Newton’s method (see Equation 9 and 10):

$$f(V_i) = 308 * HP_{min} - \left[1.3W_L + 0.6K_{adj}W_C + (20g + 0.8c)W + 29A_L + 20K_{adj}A_C\right]V_i - \left[0.03W_L + 0.01K_{adj}\right]{V_i}^2 - \left[0.3N_L + K_{adj}KN_C\right]{V_i}^3 \tag{9}$$

$$V_{i+1} = V_i - \frac{f(V_i)}{f'(V_i)} \tag{10}$$

where $W$ is the total gross weight of the train in tons, $g$ is percentage gradient of terrain, and $c$ is the degree of curvature, $K_{adj}$ is an adjustment factor to modernize the Davis equation and $K$ is the drag coefficient which varies based on the equipment selected by the user. $N_L$ is the number of locomotives, and $A_L$ and $A_C$ are the total number of axles of all locomotives and railcars, respectively. $f'(V_i)$ is the derivative of $f(V_i)$. All other variables remain as earlier defined.

#### 4.1.5.2 Throttle Controls

CTRIT uses an algorithm similar to the General Automatic Train-controller (GAT) developed for TEM. According to Drish (2004), GAT uses a set of train-handling rules to form a “knowledge base” that directs the controller to operate the train and minimizes the speed error (difference between the current reference speed and the actual train speed). Using input information about acceleration, train speed, and track position, a set of "IF THEN" train-handling rules determine when a command is to be executed to obtain the desired operation of the train (Start, Accelerate, Maintain Reference Speed, Decelerate, and Stop) (Drish, 2004).

CTRIT currently uses the simplest knowledge base in GAT which “assumes that the throttle is the only control available to the controller” (Drish, 2004). The throttle controller uses the speed, $V_i$, as well as the posted speed to determine which throttle position the train should be operating at each incremental step distance. The knowledge base consists of only three action rules and assumes that the only available train control is the throttle. It therefore does not use the dynamic and air brake controls. It automatically "anchors" the train with a full air brake setting of 100% when the train comes to a stop (Drish, 2004). The knowledge base used in CTRIT is as follows:

```
Rule 1
If   PRO_ERR  is less than PRO_LOW,
And  REC_THR  is greater than THR_SET,
Then INC_THR.
Rule 2
If   SPD_ERR is less than SPD_LOW,
Then INC_THR.
Rule 3
If   PRO_ERR is greater than or equal to PRO_LOW,
And  REC_THR is less than THR_SET
Then DEC_THR.
```

According to Drish (2004), "Rule 1 and Rule 3 each use a condition on the projected speed error, PRO_ERR, at the time of throttle/dynamic transition (9 seconds hence), and a condition on the current throttle setting, THR_SET, to increase and decrease the throttle setting, respectively. Rule 2 uses a condition on the current speed error, SPD_ERR, to increase the throttle setting. In Rules 1 and 3, PRO_ERR is compared to the long-term lower threshold for speed error, PRO_LOW (which has the value -1 MPH in this case), and THR_SET is compared to the recommended equilibrium throttle setting, REC_THR, which is determined by the current average grade under the train and the current reference speed. In Rule 2, SPD_ERR is compared to the short-term lower threshold for speed error, SPD_LOW (which has the value -4 MPH in this case)."

#### 4.1.5.3 Fuel Consumption

For each "step distance" increment, fuel consumption is calculated using reported fuel consumption rates (FCR), similar to those shown in Table 4, at the train's current throttle position (THR_SET) multiplied by the time the throttle stays at that position – which is determined by the "step distance" and running speed (Equation 11).

$$FC = FCR(Throttle\ Position) \times \frac{Step\ Distance}{V_i} \tag{11}$$

Table 4: Typical Fuel Consumption Rates (Drish, 2004; Horizon Rail, 2012)

| 3800 HP - EMD SD60 | | |
|---|---|---|
| **HP** | **Throttle** | **FCR(Throttle) Gal/Hour** |
| 0 | 0 | 3.1 |
| 189 | 1 | 12.0 |
| 418 | 2 | 22.8 |
| 943 | 3 | 47.8 |
| 1,298 | 4 | 64.9 |
| 1,749 | 5 | 86.9 |
| 2,530 | 6 | 123.2 |
| 3,324 | 7 | 157.5 |
| 3,808 | 8 | 184.7 |

| 3000 HP - EMD SD40 | | |
|---|---|---|
| **HP** | **Throttle** | **FCR(Throttle) Gal/Hour** |
| 0 | 0 | 0.8 |
| 200 | 1 | 7 |
| 390 | 2 | 25 |
| 710 | 3 | 41 |
| 1,085 | 4 | 57 |
| 1,420 | 5 | 79 |
| 1,830 | 6 | 108.5 |
| 2,375 | 7 | 145.8 |
| 3,000 | 8 | 167.7 |

### 4.1.6 Travel Time, Rail Capacity, and Delay Calculations

Estimated travel time can be calculated by finding the travel time for each step distance based on the estimated running speed of step. CTRIT then allows the user to input any idle time experience while making the trip. This can include any time spent waiting in sidings or in a terminal along the route. To account for delays, CTRIT integrates the CN parametric model (Krueger, 1999; Lai and Barkan, 2009), which measures subdivision capacity and evaluates the effect of improvements on the system. The relationship between train delay (hour/train) and the traffic volume curve and key parameters were developed on the basis of a series of regression analyses and found to be:

$$Train\ delay = A_o e^{B_o V} \tag{12}$$

where coefficient $A_o$ represents the relationship between train delay and parametric values and is unique for each combination of parameters defined by the plant, traffic, and operating conditions of a subdivision; $B_o$ is constant; and $V$ is traffic volume (trains/day) (Krueger, 1999; Lai and Barkan, 2009).

The user can also specify if any refueling or crew changes are made as well as the time the stop would take. Once this information is entered, the total trip travel time ($T_T$) is calculated by summing the running time ($T_s$), train delay ($T_d$), idle time ($T_i$), and crew change or refueling time ($T_{cr}$) and $N_{cr}$ is the number of stops (see Equation 13)

$$\mathrm{T_T} = \sum_{\mathrm{i=1}}^{N_s} T_s + T_d + T_i + (T_{cr} * N_{cr}) \tag{13}$$

### 4.1.7 Cost Output

Cost outputs from the model include crew labor cost, capital and investment costs, maintenance costs, fuel costs, and loading and unloading costs. These costs are then aggregated to find the total cost, costs per mile, costs per payload ton-mile, and costs per trailing ton-mile.

#### 4.1.7.1 Crew Labor Cost Module

Although previous work indicates that crew costs can be estimated by distance (*5*), a more realistic and effective method of crew wages can be applied. CTRIT allows the user to input crew information and determines labor cost on an hourly basis. Some of these inputs include the number of crew members (NumOfCrewMembers), number of crew changes (NumOfCrewChanges), average hourly wage per crew member (AvgHourWage), maximum labor time before accruing overtime pay (MaxLaborTime), an overtime multiplier (OvertimeMultiplier), and an overtime threshold. The algorithm below is used in CTRIT to determine the total crew labor costs ($C_{labor}$) along a route:

```
Condition 1
       If (NumOfCrewChanges = 0
       And EstTotalTripTime <= MaxLaborTime)
       Then LaborCost = EstTotalTripTime * NumOfCrewMembers * AvgHourWage

Condition 2
       If NumOfCrewChanges = 0
       And EstTotalTripTime <= (MaxLaborTime + OvertimeThreshold)
       And EstTotalTripTime > MaxLaborTime)
       Then LaborCost = MaxLaborTime * NumOfCrewMembers * AvgHourWage +
           (EstTotalTripTime - MaxLaborTime) * NumOfCrewMembers * AvgHourWage *
           OvertimeMultiplier

Condition 3
       If NumOfCrewChanges > 0
       Then  LastCrewTime = EstTotalTripTime - MaxLaborTime * NumOfCrewChanges
             If LastCrewTime <= MaxLaborTime
                 Then LaborCost = (MaxLaborTime * NumOfCrewMembers *
                  AvgHourWage * NumOfCrewChanges) + (LastCrewTime *
                  NumOfCrewMembers *  AvgHourWage)
             If  LastCrewTime <= (MaxLaborTime + OvertimeThreshold)
                 Then LaborCost = MaxLaborTime * NumOfCrewMembers * AvgHourWage
                      * NumOfCrewChanges + MaxLaborTime * NumOfCrewMembers *
                      AvgHourWage + (LastCrewTime - MaxLaborTime) *
                      NumOfCrewMembers * AvgHourWage * OvertimeMultiplier
             ElseIf LastCrewTime > MaxLaborTime
                 Then LaborCost = MaxLaborTime * NumOfCrewMembers * AvgHourWage
                      * NumOfCrewChanges + MaxLaborTime * NumOfCrewMembers *
                      AvgHourWage + (LastCrewTime - MaxLaborTime) *
                      NumOfCrewMembers * AvgHourWage * OvertimeMultiplier
              Else LaborCost = MaxLaborTime * NumOfCrewMembers * AvgHourWage +
                   (EstTotalTripTime - MaxLaborTime) * NumOfCrewMembers *
                   AvgHourWage * OvertimeMultiplier
```

This algorithm assumes that labor is paid by the hour and includes some overtime pay if work time exceeds the limit of maximum allowable labor time (MaxLaborTime). For overtime pay, which is usually some multiple of the normal hourly wage, CTRIT uses 1.5 times the hourly wage as a default for the overtime multiplier

(OvertimeMultiplier). Some threshold (OvertimeThreshold) is also considered in which it is more economical to pay someone to work overtime, rather than trying to enforce a crew change. This leads to three basic conditions that CTRIT uses to capture the appropriate labor cost as shown in Figure 2.

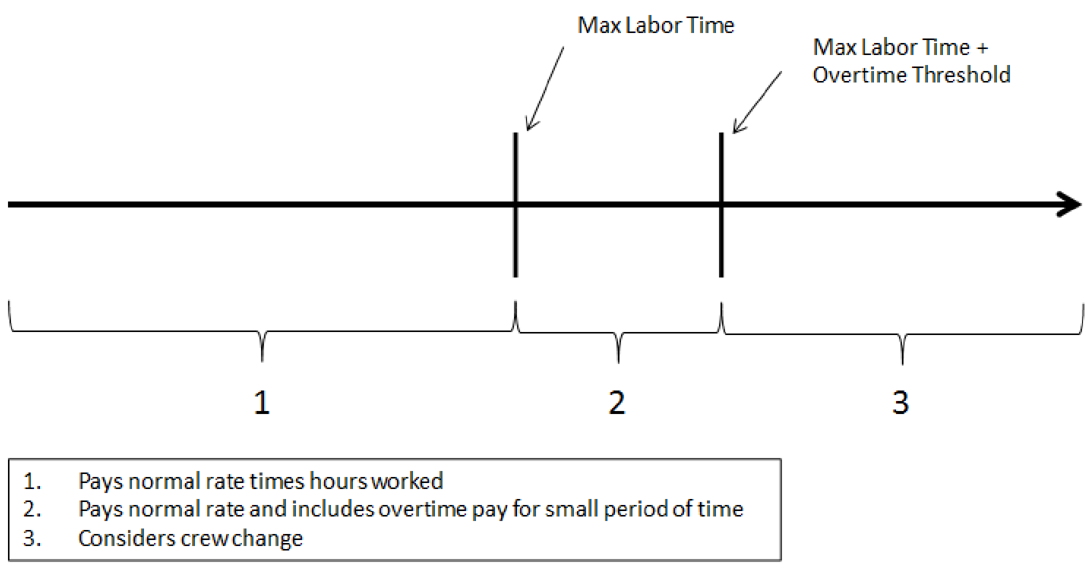


Figure 2: Labor Conditions

#### 4.1.7.2 Capital Cost and Investment Cost Module

Capital and investment costs are the most difficult to model (Seedah et al., 2011). Investments by rail companies are extremely private and most capital costs vary by location and/or provider. Some of the capital costs include large investments in the construction of rail tracks, structures, rail yards, signals, cars, and locomotives. Because obtaining adequate data to model these costs would be nearly impossible, CTRIT currently uses a straight-line depreciation equation where trip depreciation is determined for each car and locomotive by multiplying hourly depreciation by the total trip time as shown in Equation 14.

$$C_{cap} = \sum_{i}^{N} \frac{Cost\ of\ Asset_i - Scrap\ Value_i}{Life\ Span\ (years) \times 8760 \frac{hrs}{years}} \times \mathrm{T_T} \tag{14}$$

#### 4.1.7.3 Maintenance Cost Module

The maintenance cost module includes track, car, and locomotive maintenance. These costs are calculated using a per mile system average rate (Seedah et al., 2011). CTRIT allows the user to input the cost per mile for each of these maintenance categories but some default values are given based on rail expert recommendations. Total maintenance cost ($C_M$) is determined using Equation 15.

$$C_M = c_{m_T}(N_C + N_L) + c_{m_c}N_C + c_{m_l}N_L \tag{15}$$

where $c_{m_T}$ is track maintenance cost per mile per car and locomotive, $c_{m_c}$ is the car maintenance cost per mile, and $c_{m_l}$ is the locomotive maintenance cost per mile. $N_c$ is the number of cars in the train and $N_L$ is the number of locomotives.

#### 4.1.7.4 Fuel Cost Module

The fuel cost module in CTRIT allows the user to change the price per gallon of fuel in order to estimate the total fuel cost for a haul. The estimated total gallons of fuel used come from the Train-In-Motion module. This is simply multiplied by the price per gallon to get the total fuel cost.

$$C_F = f_{pg} * FC_g \tag{16}$$

where $C_F$ is the total fuel cost for the trip, $f_{pg}$ is the specified fuel price per gallon, $FC_g$ is the total estimated fuel consumption for the trip in gallons.

#### 4.1.7.5 Loading and Unloading Cost Module

This module tries to capture the cost of loading and unloading the train. Considering the challenges for shipments by rail to compete with trucking in this area, it is important to try and incorporate the loading and unloading costs associated with freight rail. CTRIT allows the user to specify loading and unloading cost per container. These per container costs are then multiplied by the number of containers being shipped, which comes from the Equipment and Cargo selection module.

$$C_{LU} = (L_c + U_c) * N_{con} \tag{17}$$

where $C_{LU}$ is the total cost for loading and unloading the train, $L_c$ is the specified loading cost per container, $U_c$ is the specified unloading cost per container, and $N_{con}$ is the number of containers being shipped.

#### 4.1.7.6 Total Cost

This Total cost of moving a single train over a user-specified route is determine as

$$C_{Tot} = C_{Labor} + C_{Cap} + C_M + C_F + C_{LU} \tag{18}$$

## 4.2 CHAPTER SUMMARY

This toolkit can estimate the comparative costs on any rail route if given the track input data and train information. The input data requirements, as with many models, limit the easy utilization of this model. Detailed track data is complicated to derive and usually rail companies are hesitant on making such data available due to competitive concerns. The data needed to run this model for any scenario include milepost, elevation, posted speeds, and curvature data.

The next chapter describes how to determine what combination of traffic, distance, curvature, rise and fall, and gradient gives the best economic outcome for railroad operations.

It is also necessary to develop a method to obtain this data without depending on the rail companies. If the track input data can be easily acquired, this rail model can be extremely beneficial for corridor analysis. A brief description on how data can be acquired through the use of geographical information system technologies is also presented in section 5.2.

# Chapter 5: Rail Alignments and Hay's Location Process

Rail infrastructure is most important for interstate trade because of its efficiency in long haul movements. However, railroads in the United States will face capacity constraints should freight traffic continue to increase (Cambridge Systematics, 2007). Rail demand is estimated to rise by at least 37% by tonnage and 86% by value (FAF 3, 2009) between now and 2040. The current infrastructure can only handle this demand if investments are made in double-tracking existing lines to remove various bottlenecks in the system, providing for new sidings, or constructing alternative routes (Cambridge Systematics, 2007).

Hay (1982) developed a route location process which determines what combination of traffic, distance, curvature, rise and fall, and gradient gives the best economic outcome for railroad operations. His route location process is one of the few efforts aimed at comparing route alternatives from a purely economically viable approach without the need to intrude on the privacy of railroad companies.

## 5.1 The Location Process by Hay

Hay's location process determines the rate of return for any given railroad route as a measure of its economic benefit (Hay, 1982). It was not intended to provide precise answers but can be used as a comparative tool for planning purposes, for example, determining those traffic combinations and route characteristics which give the best economic outcome. Input data required by the location process include:

- Annual gross and net tonnage,
- Revenue per ton mile,
- Total distance of route,

- Total central angle,
- Class of total rise and fall,
- Ruling grade,
- Construction cost per mile,
- Motive power, and
- Equipment to be hauled

Once the necessary input data is determined, the location process calculations can be performed for each line being compared. The first calculation determines estimated route revenues using the Equation 1 where R is the total revenue, $T_g$ is the gross tonnage, D is the route distance, and $R_{ptm}$ is the revenue per ton mile, which is either an estimate or a system wide average.

$$R = T_g * D * R_{ptm} \tag{1}$$

Construction cost is then determined using Equation 2, where $C_c$ is the total construction cost, and $C_{cptm}$ is the construction cost per mile for the route. Note that construction costs can vary greatly depending on the routes chosen for comparison.

$$C_c = D * C_{cptm} \tag{2}$$

The next calculation is the estimated operating costs for the distance of the route. This is done by assuming that the shorter of the two routes for comparison is the base case and the other is calculated off of that base case by introducing a distance cost factor ($F_D$) that is intended to correlate the non-base case operating cost to the base case operating cost. The calculation for the base case is performed using Equation 3 where $OC_{Dbase}$ is the operating cost for the distance traveled on the base case route, Tg is the gross tonnage for both directions, $D_{base}$ is the distance of the base case route, and $C_{kgtm}$ is the system wide average cost per thousand ton miles.

$$OC_{Dbase} = \frac{T_g}{1000} * D_{base} * C_{kgtm} \quad (3)$$

To find the other route's costs, a distance factor ($F_D$) must be determined. Hay (1982) calculated this by summing published operating costs percentages from the American Railway Engineering Association (Hay, 1982). This was then multiplied by the base case cost as shown in Equation 4 where $OC_D$ is the operating cost for the distance traveled on the non-base case route, and D is the distance of the non-base case route.

$$OC_D = OC_{Dbase} + \frac{T_g}{1000} * (D\text{-}D_{base}) * C_{kgtm} * F_D \quad (4)$$

The operating cost for curvature is then determined using Equation 5 where $OC_C$ is the operating cost for the curvature along the route, $A_{TC}$ is the total central angle, and $F_C$ is the curvature factor. Again, $F_C$ was determined by published percentages from the American Railway Engineering Association (Hay, 1982).

$$OC_C = \frac{T_g}{1000} * \frac{A_{TC}}{528} * C_{kgtm} * F_C \quad (5)$$

The next operational costs the must be considered is the effect of rise and fall along the route. This is down by breaking down rise and fall in three classes: A, B, and C

(Hay, 1982). Class A gradients are so small that no throttle changes or breaking is necessary. These grades usually don't affect the trains speed unless there are long successions of these classes of grades. Class A gradients are usually considered to be 30 feet or less (Hay, 1982). Class B gradients are those of which small throttle adjustments must be made but still no breaking required. These grades usually fall between more than 30 feet up to 0.06 % (Hay, 1982). Class C gradients usually required considerable additional power by increasing the throttle and brake application when the train is descending (Hay, 1982).

Since Class A gradients are minimal, only the effect of Class B and C grades are considered for calculation. It is assumed that an average value of train resistance is 10 lbs/ton, meaning that would be the same power as a 0.50% gradient for 26.4 ft/mile (Hay, 1982). The Class B calculation can be found using Equation 6 where $OC_{RFB}$ is the operating costs for rise and fall class B grades, $RF_{TB}$ is the total rise and fall for the class B grades, and $F_{RFB}$ is the rise and fall factor for class B grades.

$$OC_{RFB} = \frac{RF_{TB}}{26.4} * \frac{T_g}{1000} * C_{kgtm} * F_{RFB} \tag{6}$$

Class C grades have a similar calculation (Equation 7) but must also account for the ruling grade when necessary where $OC_{RFC}$ is the operating costs for a rise and fall class C grades, $RF_{TC}$ is the total rise and fall for the class C grades, and $F_{RFC}$ is the rise and fall factor for class C grades.

$$OC_{RFC} = \frac{RF_{TC}}{26.4} * \frac{T_g}{1000} * C_{kgtm} * F_{RFC} + RG_F \tag{7}$$

$RG_F$ is only added when the ruling grade is considered. The calculation of $RG_F$ is shown in Equation 8.

$$RG_F = 0.03*(\frac{RF_{TC}}{26.4}*\frac{T_g}{1000}*C_{kgtm}*F_{RFC}) \tag{8}$$

Next, the required drawbar pull of the train must be calculated by finding the resistances of the train for both routes in each direction (Equation 9). An arbitrary locomotive or car type can be selected as s representation of which equipment will most likely be used on the route.

$$R_L = \left(1.3 + \frac{29}{\frac{w_L}{A_L}} + bV + \frac{cAV^2}{\left(\frac{w_L}{A_L}\right)*n}\right) * W_L * K_{adj} + W_L * 20 * G \tag{9}$$

Here, $R_L$ is the locomotive resistance, $w_L$ is weight of a single locomotive, n is the number of locomotives, $A_L$ is the number of locomotive axles, $V$ is train speed, $A$ *is* locomotive cross-sectional area, $b$ is the coefficient of flange friction, c is the drag coefficient of air, $W_L$ is total weight of all locomotives, $K_{adj}$ is an adjustment factor to modernize the Davis equation, and G is the grade for that section as a percent. For rail cars, Equation 9 can be used by simply changing the variables to their respective car properties.

Drawbar pull can then be calculated by subtracting the locomotive resistance from the motive power (tractive effort). Equation 10 shows the final drawbar pull calculation where DBP is the total drawbar pull for each route and direction, TE is the tractive effort supplied by the locomotives, and $R_L$ is the locomotive resistance found from Equation 9.

$$\mathrm{DBP} = \mathrm{TE} - \mathrm{R_L} \tag{10}$$

Train tonnages can then be calculated for each route and direction by simply dividing the drawbar pull by the car resistances shown in Equation 11.

$$\mathrm{TT} = \frac{\mathrm{DBP}}{\mathrm{R_c}} \tag{11}$$

The total number of trains (N) can then be defined by dividing the gross tonnage by the train tonnage (TT) as shown in Equation 12. Obviously this can be converted into the number of trains per day by dividing by the number of operating days in the year which is usually 365 days.

$$\mathrm{N} = \frac{\mathrm{T_g}}{\mathrm{TT}} \tag{12}$$

Hay (1982) then finds an estimated cost of additional trains by using the difference in traffic densities of the routes. It assumes that any extra traffic on one line creates additional costs. Using a pre-defined cost per train mile value ($\mathrm{E}_{ptm}$) and the percentage of change ($\mathrm{F}_{pnt}$) in operating expenses affected by the number of trains, the cost of an additional train $\mathrm{C_{AT}}$ can be found as

$$\mathrm{C_{AT}} = (\mathrm{N_B} - \mathrm{N_A}) * \mathrm{D} * \mathrm{E_{ptm}} * \mathrm{F_{pnt}} \tag{13}$$

where $\mathrm{N_B}$ number of trains for the route with more trains, $\mathrm{N_A}$ is the number of trains for the route with lesser trains.

Total operating cost, $OC_{Total}$, is then determined by summing the individual costs for distance, curvature, rise and fall, and traffic density for each route (see Equation 14), where $C_{AT}$ is only included for the route with the higher train traffic flows to account for any costs associated with the increased volumes.

$$OC_{Total} = OC_D + OC_C + OC_{RF} + C_{AT} \tag{14}$$

Finally, the rate of return for each route is determined to aid in the decision of which route is more cost effective and economical (see Equation 15). The route with the higher rate of return is the preferable route.

$$ROR = \frac{R\text{-}OC_{Total}}{C_c} \tag{15}$$

A limitation of Hay's location process is that the cost values used in the example calculations (Hay, 1982) were developed in the 1970's which are much different than what currently exists. It is thus important that those values be replaced with more current data when performing analysis.

### 5.2 ROUTE DATA ACQUISITION MODEL

Acquiring the necessary route data for the location process seems to be a challenge for planners. A route data acquisition model was therefore developed to allow users to determine the elevation profile of any existing or planned rail route, thus providing information on grades. The route data acquisition model requires two GIS data sources: 1) railroad network data, and 2) the Digital Elevation Models (DEM) which are a three-dimensional representations of a terrain's surface. DEM models for the United

States can be acquired from the United States Geological Survey (USGS) National Elevation Dataset (NED). According to USGS (USDOI, 2006), “the NED is updated on a nominal two month cycle to integrate newly available, improved elevation source data. The data is derived from diverse source data that are processed to a common coordinate system and unit of vertical measure. NED data are distributed in geographic coordinates in units of decimal degrees, and in conformance with the North American Datum of 1983 (NAD 83).” Elevation data from the NED is available nationally at resolutions of 1 arc-second (about 30 meters) and 1/3 arc-second (about 10 meters), and in limited areas at 1/9 arc-second (about 3 meters), except in Alaska where many parts of data is available only at 2 arc-second (about 60 meters) grid spacing (USDOI, 2006). For this model, a 1 arc-second resolution - 30 meters, 100 feet or 0.01 miles – is sufficient. When the rail network is overlaid on top of the DEM data file, it is possible to obtain the digital elevations of the network at 0.01 mile intervals. Using a GIS application, alternative routes can be drawn and elevation data obtained. The data can then be processed and used as a route’s distance and elevation profile.

In order to validate the route data acquisition model, the profile of an existing rail line from Houston to Fort Worth was obtained and the comparison presented in Figure 3. A visual assessment of the two datasets displays few differences in elevations changes. These changes correlate to track grade changes that are necessary for accurately determining a route’s ruling grade. A limitation of using the data acquisition model is its inability to accurately capture elevated structures such as overpasses and bridges. The GIS profile data follows the land’s topography and elevated structures may not be captured. This limitation can be mitigated by analyzing extreme changes in elevation with a map that shows riverbeds, low-lying spots, bridges and overpasses, and adjusting the points accordingly using available data or linear interpolation where possible. For example, most rail lines are built with grades of less than 2%, and for grades greater than 3%, it is recommended that modelers investigate discrepancies in the data as this may be an error in the model's output.

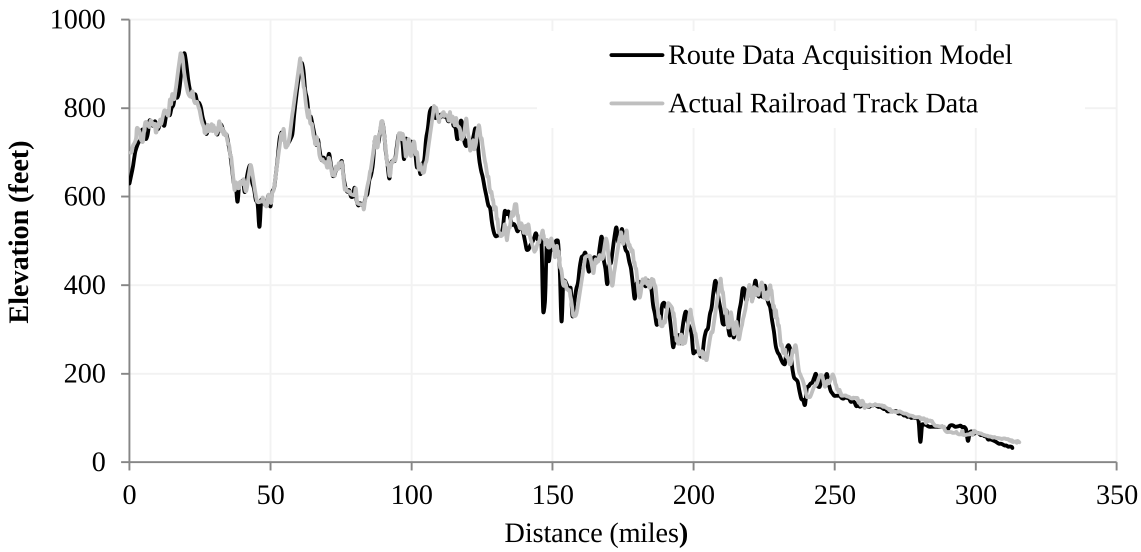


Figure 3: Elevation Profiles Comparing the Two Datasets – Model (darker color) and Actual Railroad Track Data (gray color)

## 5.3 CHAPTER SUMMARY

Hay's location process model in combination with the route data acquisition model creates a solid method of analyzing and comparing rail routes. The use of the data acquisition model obviates the need to obtain track characteristics from the rail companies making it easier analyze corridors. This becomes especially important for corridors with multiple rail routes or to test the feasibility of new routes. The next chapter presents a host of sensitivity analysis and case studies to validate the proposed rail toolkit.

# Chapter 6: Sensitivity Analysis and Case Studies

In 2007, it was estimated that 23.7 million tons of goods were exported between Dallas and Houston, and this number is forecasted to grow to 43.9 million tons by 2040 (FAF 3, 2012). Of this number, 77.9% was moved by truck and 3.5% was moved by rail (FAF 3, 2012). The top five commodities moved by rail include plastics/rubber, basic chemicals, coal, waste/scrap, and fertilizers (FAF 3, 2012). The top 5 commodities moved by truck are waste/scrap, base metals, basic chemicals, food, and motorized vehicles (FAF 3, 2012). This freight corridor is an essential part of the Texas economy considering the Port of Houston for international trade and the Alliance Intermodal Facility in Dallas-Fort Worth which serves inland trade. This corridor is worth studying as it provides an opportunity for modal shift from truck to rail.

## 6.1 Rail Model Case Study and Sensitivity Analysis

For this study, the rail track data for the route stretching from Houston to Dallas-Fort Worth was acquired as illustrated in Figures 4 and 5. The total distance of the track is 318 miles with the highest elevation at 913 feet and the lowest elevation at 45 feet. An intermodal train using this facility was simulated to test the sensitivity of the model and estimate railroad operating costs and travel times on the corridor. The train is assumed to be a high priority train with no stops along the route.

The following scenarios were tested: 1) effect of HPTT (horsepower per trailing ton) ratios and number of locomotives, 2) effect of fuel price changes, and 3) effect of cargo weight.


Figure 4: Case Study Route between Houston and Dallas/Fort Worth

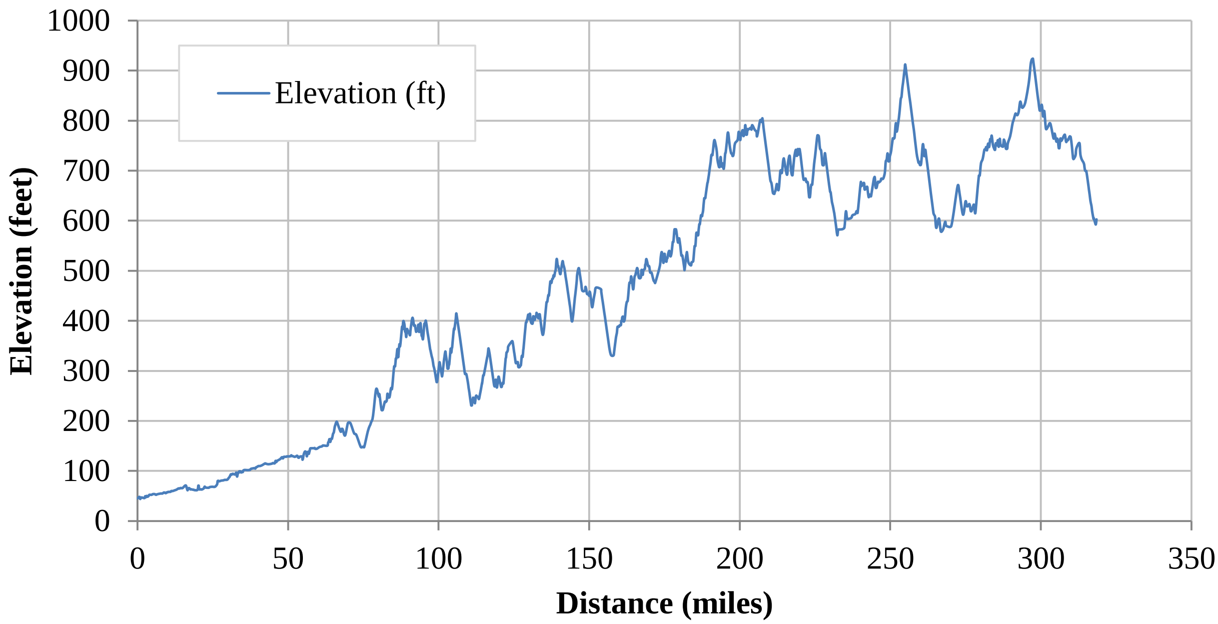


Figure 5: Track Data for Houston-Fort Worth Route

Labor cost, maintenance cost, price of fuel, and loading and unloading costs were taken from a previous study (Seedah et al., 2011) and adjusted for inflation (US Inflation, 2012). Rail inputs are as follows unless specified otherwise:

- Distance of route: 318 miles,
- Tare weight of one 40-ft container: 4.2 tons,
- Tare weight of one container carrier car: 17.60 tons,
- Utilization ratio: 100%
- Engine Efficiency: 85%
- Locomotive horsepower: 4,000 HP
- Number of crew members: two,
- Average Crew wages: $31.75 per hour per crew member (Salary, 2012),
- Diesel Fuel price: $3.00/gal,
- Track maintenance: $0.53 per mile,
- Car maintenance: $0.13 per mile,
- Locomotive maintenance: $2.21 per mile, and
- Loading Cost: $75, Unloading Cost: $75.

### 6.1.1 Effect of HPTT Ratio and Number of Locomotives

Many different scenarios were tested to determine the effect of HPTT (horsepower per trailing ton) ratio and number of locomotives on rail line hauls operations. The results of each scenario are presented in Tables 5 and 6. These scenarios simply represent the same train running at different HPTT ratios.

Table 5 consists of a train with two locomotives powering it and Table 6 considers 3 locomotives. These scenarios all involve a 110 double-stacked container train with a cargo weight of 15 tons with the assumption that all the trains were 100% fully loaded. HPTT ratios of 1, 1.5, 2, 2.5, and 3 were all tested.

Table 5: Case study and Results for Train with Two locomotives

| ***Variables*** | **Scenario 1** | **Scenario 2** | **Scenario 3** | **Scenario 4** | **Scenario 5** |
|---|---|---|---|---|---|
| Number of Containers | 110 double stack | 110 double stack | 110 double stack | 110 double stack | 110 double stack |
| Cargo weight per container (tons) | 15 tons | 15 tons | 15 tons | 15 tons | 15 tons |
| HPTT Ratio | 1 | 1.5 | 2 | 2.5 | 3 |
| Number of Locomotives | 2 | 2 | 2 | 2 | 2 |
| Total Locomotive HP | 8,000 | 8,000 | 8,000 | 8,000 | 8,000 |
| ***Model Output*** | | | | | |
| Train Weight (tons) | 3080 tons | 3080 tons | 3080 tons | 3080 tons | 3080 tons |
| Fuel Consumed (gallons) | 1824 | 1915 | 1980 | 1940 | 1885 |
| Cost per train weight ton-mile (cents) | | | | | |
| Cost per payload ton-mile (cents) | 6.96 cents | 6.99 cents | 7.01 cents | 6.98 cents | 6.95 cents |
| Cost per trailing ton-mile (cents) | 3.73 cents | 3.74 cents | 3.76 cents | 3.74 cents | 3.72 cents |
| Trailing ton-mile moved per gallon | 607.62 | 578.79 | 559.79 | 571.10 | 587.85 |
| Payload ton-mile moved per gallon | 288.09 | 274.43 | 265.42 | 270.78 | 278.72 |
| Estimated Average Speed | 23 mph | 26 mph | 28 mph | 29 mph | 30 mph |
| Estimated Travel Time | 14.3 hours | 12.7 hours | 12.0 hours | 11.6 hours | 11.3 hours |

The results of all five scenarios for the two locomotive configuration indicated that the most cost effective scenario per ton-mile was scenario 5 where the average speed was 30 mph and the payload ton-miles per gallon of fuel was 587.85. This case used an HPTT ratio of 3 and took advantage of the lower travel time, only costing 6.95 cents per payload ton-mile to move the freight. The least cost effective scenario was scenario 3 in which the fuel consumption was the highest and the cost per ton-mile was 7.01 cents. Fuel consumption for all five scenarios ranged between 1,824 to 1,980 gallons. Estimated average travel speeds for all the configurations ranged between 23 mph and 30 mph, and travel times ranged between 11.3 hours and 14.3 hours. As expected, the train with the higher HPTT ratio runs at faster a speed than that of the lower HPTT ratios. This is because at higher HPTT ratios the amount of power available to move the train increases.

Another key factor in this case study is the comparison of the model's ton-mile moved per gallon of fuel consumed. From all 5 scenarios, the ton-mile moved per gallon of fuel ranged between 571 to 608 ton-miles per gallon of fuel. The published nationwide average for Class 1 railroads is estimated at 480 ton-miles per gallon of fuel by the Association of American Railroads (2012). In addition, a recent FRA study (ICF, 2009), determined that for intermodal movements involving 2 locomotives, fuel consumption ranged between 588 and 849 per trailing ton-mile per gallon, and 226 and 512 per payload weight ton-mile per gallon (ICF, 2009).

The results of all five scenarios for the three locomotive configurations also indicated that the most cost effective scenario per ton-mile was scenario 1 (see Table 6). This case used an HPTT ratio of 1 and although the train took longer to get there, it only costs 7.32 cents per ton-mile to move the freight. The least cost effective scenario was scenario 4 in which the fuel consumption was the highest and the cost per ton-mile was 7.41 cents. Fuel consumption for all five scenarios ranged between 2,136 to 2,394 gallons. Estimated average travel speeds for all the configurations ranged between 24 mph and 32 mph, and travel times ranged between 10.7 hours and 14.0 hours. Once again, the train with the higher HPTT ratio runs at faster speeds than that of the lowest HPTT.

Table 6: Case study and Results for Train with Three locomotives

| ***Variables*** | **Scenario 1** | **Scenario 2** | **Scenario 3** | **Scenario 4** | **Scenario 5** |
|---|---|---|---|---|---|
| Number of Containers | 110 double stack | 110 double stack | 110 double stack | 110 double stack | 110 double stack |
| Cargo weight per container (tons) | 15 tons | 15 tons | 15 tons | 15 tons | 15 tons |
| HPTT Ratio | 1 | 1.5 | 2 | 2.5 | 3 |
| Number of Locomotives | 3 | 3 | 3 | 3 | 3 |
| Total Locomotive HP | 12,000 | 12,000 | 12,000 | 12,000 | 12,000 |
| ***Model Output*** | | | | | |
| Train Weight (tons) | 3080 tons | 3080 tons | 3080 tons | 3080 tons | 3080 tons |
| Fuel Consumed (gallons) | 2136 | 2253 | 2320 | 2394 | 2351 |
| Cost per payload ton-mile (cents) | 7.32 cents | 7.36 cents | 7.38 cents | 7.41 cents | 7.38 cents |
| Cost per trailing ton-mile (cents) | 3.92 cents | 3.94 cents | 3.95 cents | 3.97 cents | 3.96 cents |
| Trailing ton-mile moved per gallon | 548.53 | 520.09 | 505.14 | 489.53 | 498.44 |
| Payload ton-mile moved per gallon | 245.95 | 233.19 | 226.49 | 219.49 | 223.48 |
| Estimated Average Speed | 24 mph | 27 mph | 29 mph | 31 mph | 32 mph |
| Estimated Travel Time | 14.0 hours | 12.3 hours | 11.5 hours | 11.0 hours | 10.7 hours |

Similar to the two locomotive scenarios, data for three locomotives was also selected from the FRA report. It was determined that fuel consumption ranged between

548 and 648 per trailing ton-mile per gallon, and 348 and 449 per payload weight ton-mile per gallon which further validates the output of the model (ICF, 2009).

Fuel consumption is an extremely important variable when considering freight transportation. Engines are consistently becoming more efficient even as fuel prices increase. Emissions standards are also becoming stricter making the fuel consumption more scrutinized considering fuel consumption is proportional to the particulate matter emitted into the air. Plotting the fuel consumption graphs with respect to the HPTT ratio should give insight to the fuel consumption for each locomotive configuration discussed above. Figure 6 shows the fuel consumption for these case studies.

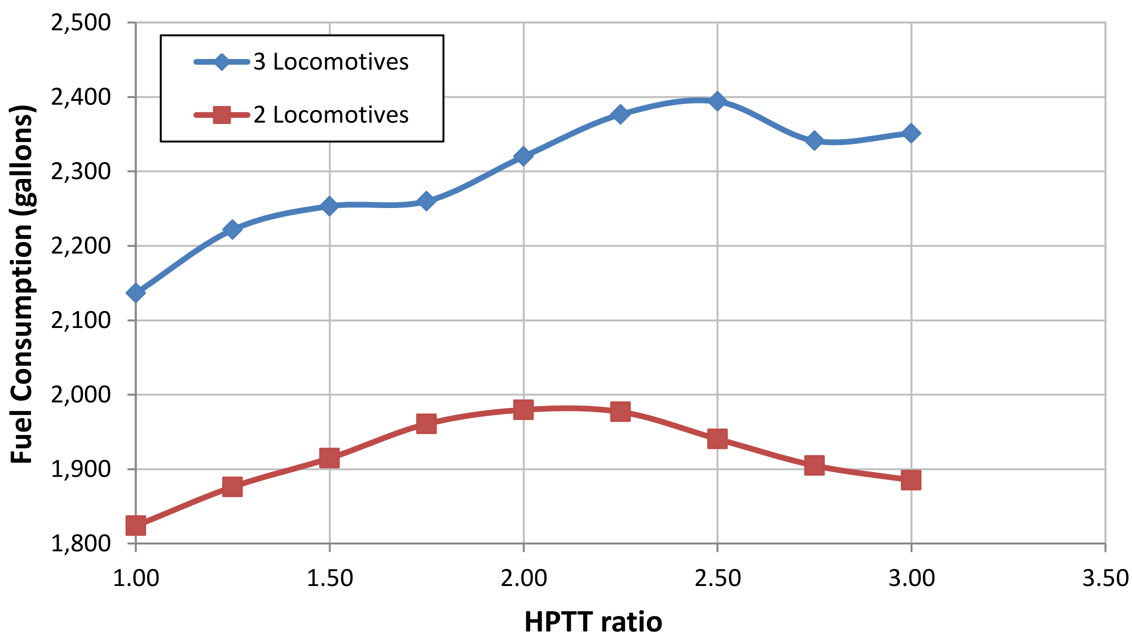


Figure 6: Fuel Consumption

### 6.1.2 Effect of Fuel Price Changes

Fuel prices have become a frequent topic of discussion for the transportation field. Fuel prices can not only impact the daily commuter's costs but also affect the price of goods in the stores. As fuel prices increase, so does the cost of freight movement. Since intermodal rail tends to be more fuel efficient per gallon than trucking, observing the effects of fuel price can be key in validating the future performance of shipping goods by freight rail as fuel prices increase.

For this case study, the two-locomotive configuration was used and fuel prices at different HPTT ratios were compared. Figure 7 shows some scenarios of the effect on total costs per ton-mile as fuel price changes.

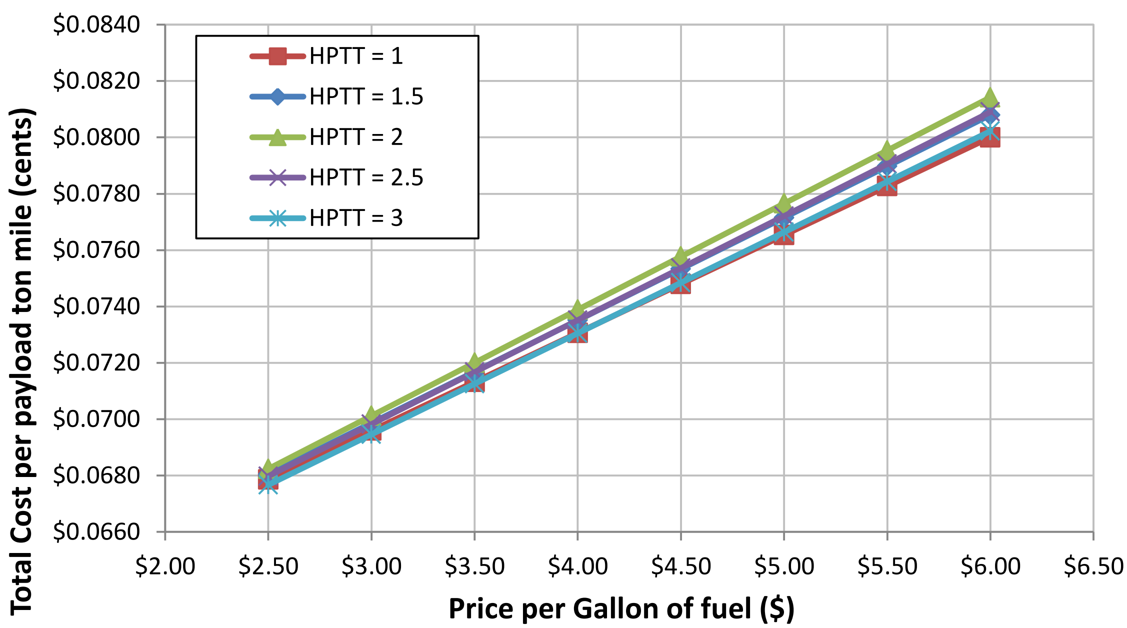


Figure 7: The Effect of Fuel Price on Total Cost per Payload Ton-Mile

Total cost per payload ton-mile ranged between 6.82 cents and 8.14 cents at HPTT ratio 2 and between 6.77 cents and 8.02 at HPTT ratio 3. As illustrated in the graph, the differences in cost per ton-miles for the different HPTT ratios increased as fuel prices increase. For example, at HPTT ratio 1, cost per ton-mile was 6.79 cents and cost per ton-mile at HPTT ratio 2 was 6.82 cents - a 0.44% percent difference – when fuel price is $2.50 a gallon. However, at $6.00 a gallon, cost per ton-mile at HPTT ratio 1 is 8.00 cents and that of HPTT ratio 2 is 8.14 cents, a 1.75% percent difference. This change is a result of the increased fuel consumption by the train at a higher HPTT ratio. It can therefore be inferred that faster trains as more costly per ton-mile than slower trains, if the value of time is ignored.

### 6.1.3 Effect of Cargo Weight

Heavier trains such as coal trains tend to be the most fuel and cost efficient trains that run in the United States. This type of train is where rail companies tend to see much of their business and where they can out compete the trucking industry. Since weight is such an important issue in regards to freight transportation, weight should be a monitored sensitivity variable considered. Figure 8 below shows how the weight of cargo effects the total costs per ton-mile for this train along this corridor for both the two and three locomotive configurations. This sensitivity was conducted with an HPTT ratio of 2 and fuel price of $3.00. As cargo weight increased 5 tons per container to 25 tons per container the cost per payload ton-mile decreased from 20.84 cents to only 4.22 cents. The trend here seems to imply that as the cargo weight increases, rail becomes more cost effective. This is why the heavier trains are more financially feasible for the railroad companies.

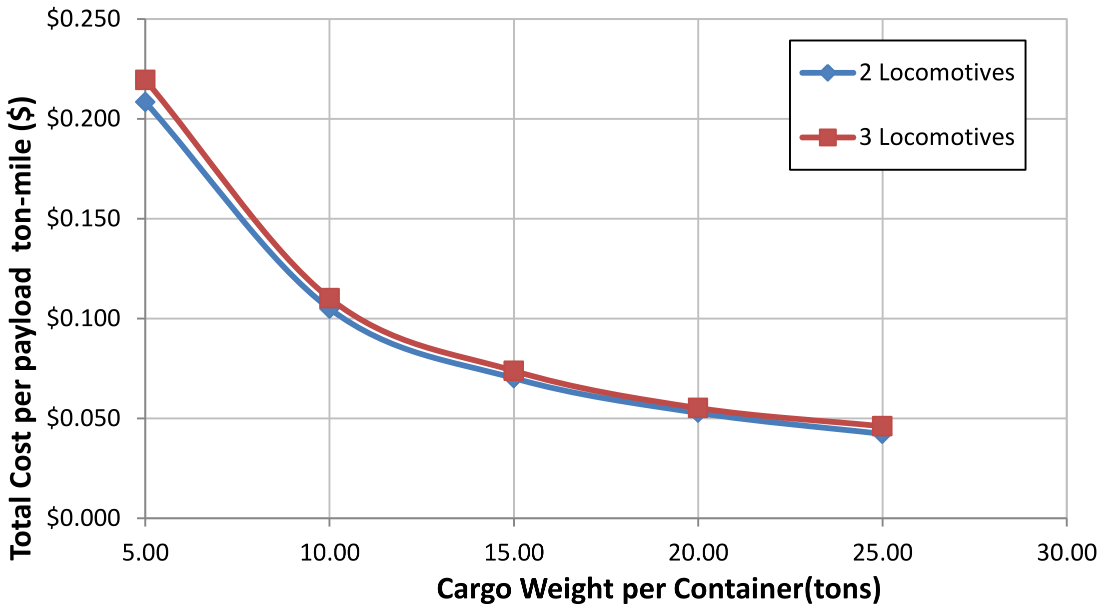


Figure 8: Impact of Cargo Weight on Total Cost per Ton-Mile

### 6.2 Enhanced Location Process Case Study

In order to better understand the capability of this data acquisition model, a hypothetical case study was performed for the Houston to Fort Worth corridor. This case study is aimed at evaluating two existing rail routes (see Figure 4) to quantify rail alignment costs and allow planners to compare the economic viability of the two alignments.

For simplicity of this case study these routes will be referred to as Line 1 (shown on the left), and Line 2 (shown on the right) of Figure 9. Line 1 is approximately 313 miles long while Line 2 is about 258 miles. The elevation profiles for both lines were acquired using the route data acquisition model and the output presented in Figure 10. The direction of the elevation profiles are from Fort Worth to Houston.

Each route is analyzed separately using the enhanced location process model which incorporates calculations from Hay's location process and data acquired from the elevation profiles. The enhanced location process model also allows users to change the input variables to allow for sensitivity analysis. Input data that can be specified by the user include annual gross tonnage, net annual tonnage, net revenue per ton mile, construction cost per mile, operating cost per mile, total central angle, motive power, and car type.

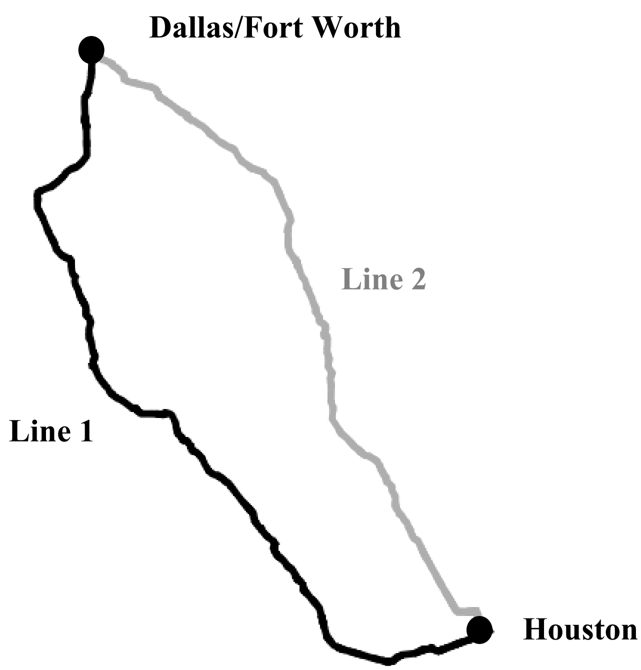


Figure 9: Case Study Corridors

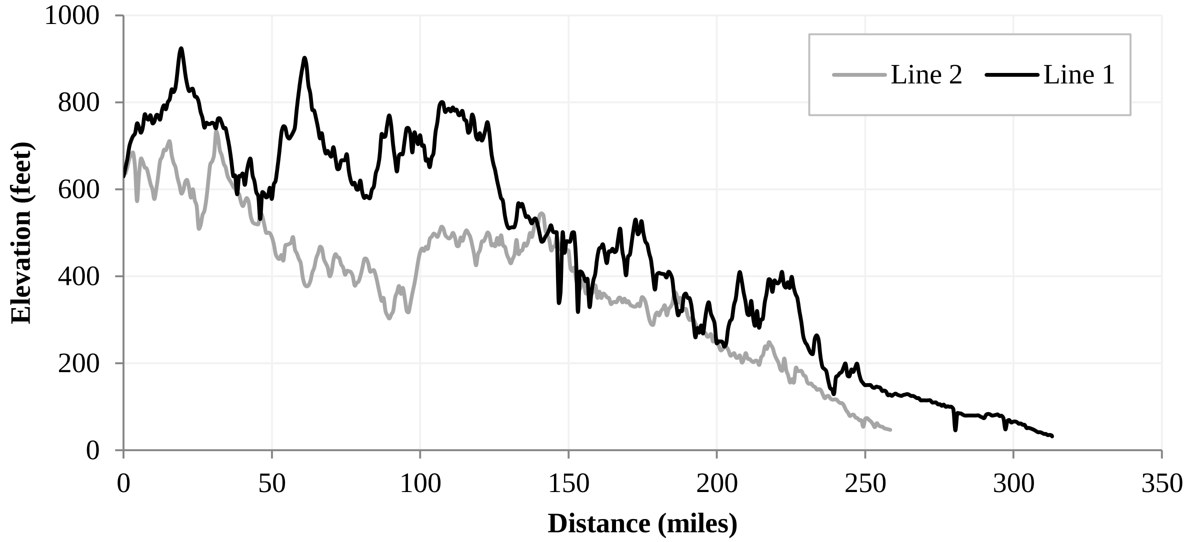


Figure 10: Elevation Profiles of Line 1 (dark color) and Line 2 (gray color)

For the hypothetical case study, the input data used is shown in Table 7. The revenue per ton mile value of 3.76 cents was taken from 2011 AAR reported Class 1 railroad operating statistics (AAR, 2012). Operating cost per ton-mile was determined by finding the operating cost per ton-mile average of two Class 1 railroads operating in the case study location (STB, 2011). Ruling grades were determined using the route data acquisition model. The distance factor ($\mathrm{F_D}$) and the percentage of change in operating expenses affected by the number of trains ($\mathrm{F}_{pnt}$) were assumed to 40% and 34% respectively, as calculated by Hay (1982). The cost of curvature and rise and fall were excluded in this case study because of lack of sufficient data.

Table 7: Input Data for Case Study

| | | Line 1 | Line 2 |
|---|---|---|---|
| Annual Gross Tonnage | Northbound | 15 million | 15 million |
| | Southbound | 12 million | 12 million |
| Net Annual Tonnage | Northbound | 10 million | 10 million |
| | Southbound | 7 million | 7 million |
| Revenue per ton mile (AAR, 2012) | | 3.760 cents | 3.760 cents |
| Operating Cost per gross ton mile (STB, 2011) | | $12.50 | $12.50 |
| Operating Cost per train mile (STB, 2011) | | | |
| Distance | | 313 miles | 258 miles |
| Ruling Grade | Northbound | 1.18% | 1.68% |
| | Southbound | 0.91% | 1.36% |
| Construction cost per mile (Lai et al., 2009) | | $5,000,000 | $5,000,000 |
| Motive Power: | 2 4,300 HP units, 4 axles, 200 tons each, 113,100 lbs. continuous tractive effort (USDOI, 2006) | | |
| Equipment and Cargo | Weight on four axles = 224,000 lbs. | | |

Output from the enhanced location process case study include Revenues, Construction cost, Operating cost - distance, Train tonnages, Number of Trains, Total Operating Cost and the rate of return (see Table 8). For this case study, revenue for the Line 1 was determined to be $38,790,021 more than Line 2, on a ton-mile basis. Construction cost for Line 1 was also $303 million more than Line 2 because of the additional 55 miles of rail track. The difference in operating costs based on distance was also was also determined to be $8,192,511. The short route, Line 2, was also determined to move more trains (2,096 northbound and southbound) annually than Line 1 which results in additional operational cost of $8,588,632 for Line 2. Total operating cost on both routes was therefore determined to be $95,197,866 and $95,593,987 for Line 1 and Line 2, respectively. The final rate of return for these two routes was estimated to be 6.8% for Line 1 and 5.4% for Line 2, therefore making Line 1 the economically viable choice of the two options.

Table 8: Case Study Findings

| | | **Line 1** | **Line 2** |
|---|---|---|---|
| Revenues | | $203,571,719 | $164,781,698 |
| Construction Cost | | $1,592,394,550 | $1,288,968,228 |
| Operating Cost - Distance | | $95,197,866 | $87,005,355 |
| Train Tonnages | Northbound | 5,403 tons | 3.834 tons |
| | Southbound | 6,914 tons | 4.451 tons |
| Number of Trains | Northbound | 2,777 (7.6 per day) | 3,913 (10.7 per day) |
| | Southbound | 1,736 (4.8 per day) | 2,696 (7.4 per day) |
| Cost of Additional Trains | | | $8,588,632 |
| Total Operating Cost | | $95,197,866 | $95,593,987 |
| Rate of Return | | 6.8% | 5.4% |

## 6.3 Chapter Summary

These case studies and sensitivity analysis of variables provided insight to the performance of the model in simulating freight rail transportation. Cargo weight per container is extremely important to the efficiency of the train, making heavier cargo more economically viable. Although this case study seems to reveal some general characteristics, for any rail route or train configuration the results can vary greatly when considering different corridors and different input variables such as car types, container types, engine efficiencies, size of locomotives, capital costs, maintenance costs, labor costs, and loading/unloading costs. These variables need further testing to determine their impact on train costs. This model can assist planners to determine how various variables influence rail operations, and incorporate some of these effects in their models at a route specific level.

# Chapter 7: Conclusion

CTRIT was developed to help planners equally compare truck and rail freight movements for specific corridors and to give insight to some key variables needed when dealing with each mode. The rail component of the model presented in this paper was designed to help planners and policy makers understand rail corridor operations and examine the opportunities and challenges for modal shifts from truck to rail. The rail component of CTRIT uses a mechanistic approach that adequately captures the effects of cargo weight, running speeds, network capacity, and route characteristics – key factors that are essential in any logistical analysis.

Building on previous work, the model can determine fuel consumption based on the specific characteristics of the rail track such as elevations, grades, and curvature; and is capable of estimating trip delays through the integration of the CN's parametric model. It allows for almost any combination of train characteristics such as type of car, type of container, cargo weight, number of locomotives, and HPTT (horsepower per trailing ton) ratio, and accounts for operating variables such as train crew costs, maintenance costs, and loading/unloading costs.

The results from the case studies do seem to reasonable. Further case studies of different corridors can give insight to the effect of each variable and the combined impact of many variables. The track characteristics of other corridors could impact the performance of trains running on them such as more mountainous regions with higher grades forcing a need for more locomotives and higher fuel consumption.

Railroads in the United States will face capacity constraints should freight traffic continue to increase as predicted. If new routes are to be developed, rail expansion options and the locations of these new routes must be determined. Constructing new routes not only includes initial capital costs but how the route fairs from an operational cost perspective. The biggest problem with addressing operational costs for alternative routes is the lack of accessible data and rail companies tend to be protective of data due to the competitive nature of their business. Finding a relatively simple but accurate way to quickly evaluate proposed railroad routes without intruding on the privacy of railroad companies could be extremely beneficial to state or regional planners when assessing alternative route options.

This paper presents on a mechanistic approach that utilizes GIS data that can be used to obtain rail track profiles and grades. This obviates the need to work with railroad companies to determine track alignments for multimodal analysis. The route data acquisition model can be applied in any part of world so far as there is reliable digital elevation model data and network data. Data from the data acquisition model can be used in conjunction with the Hay's location process to evaluate a site's topography and determine the economic viability of competing routes.

Aside from the earlier identified method for acquiring data, a setback to using CTRIT is the requirement of actual railroad track data such as exact grades, curvature and posted speeds. This obstacle can be addressed through effective collaboration and feedback with the railroad companies by planners and policy-makers.

### 7.1 Future Work and Enhancements

Although this paper presents a method for using and extracting data utilizing GIS data, the exact profile included river crossing and other cut and fill areas cannot be easily determined. Finding a method to easily process this data or developing this data in another way would greatly improve the usability of this model for a planner seeking to evaluate mode-choice options on any route.

For most input variables, CTRIT gives the option to use default values. Most of these values will change with each scenario and should be adjusted as necessary. Most of the default values are simply system averages or acquired from previous published data and research. Another limitation that rail models encounter is the ability to model the train engineer's driving behavior. Although there is a posted maximum speed that cannot be exceeded, train engineers have almost complete control on how fast they will drive the route. This allows for a variance in speeds for different drivers based on the driver's behavior. More aggressive drivers can consume a substantially higher amount of fuel than someone less aggressive. Modeling an engineer's behavior is very complex and therefore CTRIT assumes that on average the driver's operate similarly.

Dynamic and air braking behavior is also currently excluded from CTRIT because of insufficient data. Future versions of the model should include these braking options. In addition, CTRIT does not individually prioritize one train over the other. In practice, some trains are given higher priority over others to ensure a timely delivery of service. This means that some trains will have to wait in sidings while others can travel freely. CTRIT accounts only for delay time based on track capacity, and future versions of the model will provide users with the ability to assign a train's priority. Lastly, there are certain costs that cannot be captured by this model such as traffic signals, switch charges, hazmat, and other leasing costs. Railroads also face decisions of double-tracking certain routes and making additional capital investments.

The limitations specified above do not impair the utility of the model as long as the average values for key variables are calibrated, because the user is interested in determining cost differentials, not full costs. Therefore, it is recommended that CTRIT should not be used to decide or predict pricing rates, but be used as a comparison tool between truck and rail routes. This model can be used to determine freight rail movements and show that a diversion from shipping freight by truck on highways represents real economic benefits especially when considering possible future changes in prices such as fuel.

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